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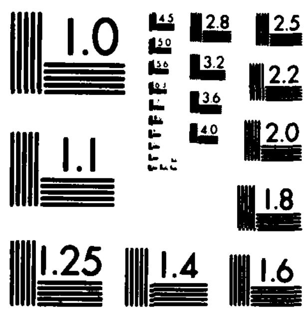
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ASPHALT RECYCLING TECHNOLOGY: LITERATURE REVIEW AND RESEARCH PLAN

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A review of current technology for the rehabilitation and maintenance of pavement surfaces by recycling was conducted. While the primary concern was asphalt concrete recycling, a brief review of portland cement concrete recycling is included. Reports of cases involving recycling technology and lessons learned are reviewed. Recommendations are presented outlining research required to advance the state-of-the-art in a manner that will permit the U.S. Air Force to fully attain the benefits of recycling technology.

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PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, Box 25, University Station, Albuquerque, New Mexico 87131, under contract F29601-76-C-0015 with the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403. This work was done during the period from 30 September 1980 to 15 April 1981.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

The findings and recommendations in this document are not to be construed as an official Department of the Air Force position. The use of trade names in this report does not constitute an official endorsement or approval of commercial products. This report may not be cited for purposes of advertisement.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

BACKGROUND

The recycling of asphalt pavements is not a recent development. Indeed, it seems to have had its beginning in this country during the earlier part of this century when the Warren Brothers used central plant operations to recycle asphalt paving surfaces (Reference 1). Recycling projects began in Singapore in 1931. In Singapore, the main consideration was economic because the roads had existed only a short time before pronounced distress became evident. After the pavements had been recycled, it was 14 years before major maintenance work was required, despite the various problems caused by World War II. The city of Bombay, India, began to recycle old asphalt pavements in 1948. Once these roads had been recycled, they lasted for nearly 30 years without major rehabilitation or reconstruction (Reference 2).

After these early efforts, little research or experimentation on asphalt recycling was attempted until the mid-1970s. At this time, the oil shortage and a scarcity of quality aggregate forced government agencies and private contractors to search out new and more economical road construction materials and processes. The quantity of pavement materials recycled in the 60-year period from 1915 to 1975 is small compared to the amount of recycling that has taken place and is expected to occur between 1975 and 1990.

The recent interest in pavement recycling can be attributed to the following situations:

1. A reduction in the funds available for transportation facilities, caused by such factors as inflation, decline in tax base, decline in or leveling of revenue from fuel taxes, and fiscal demands of other programs.

2. Materials supply problems resulting from the depletion of sources near the point of use; strictures imposed by zoning laws; increased haul distances and associated transportation costs; strict environmental codes that limit production in certain areas and require

major expenditures for the protection of air and water quality, for noise control, and for pit and quarry restoration; and use of pavement construction materials for other purposes.

3. Equipment availability problems resulting from reduced budgets, the high cost of new equipment, and other factors.

4. Manpower problems resulting from fiscal constraints on wages, which often create a deficiency of trained equipment operators and qualified engineering-oriented employees; labor-management problems; and the need to increase productivity to provide an economical operation.

5. Energy problems associated with fuel availability and cost and the urgent need to reduce energy consumption.

The reuse of asphalt concrete materials is beneficial in five basic ways: it can (1) help to stabilize the cost of pavement construction, (2) conserve petroleum and aggregate resources, (3) reduce the amount of energy required to maintain and rehabilitate pavements, (4) help preserve the environment, and (5) preserve existing pavement geometrics.

Conservation of aggregates and binders is important. Although the United States has an abundant supply of source materials for the production of quality aggregates in the foreseeable future (References 3 and 4), the materials are not evenly distributed over the country, and it has become necessary to haul aggregates over long distances. The result has been an escalation of costs and of the amount of energy consumed in constructing transportation facilities. Recycling the aggregate in old pavement will decrease the demand for aggregate and thus extend the supply at a time when sources (particularly those near urban areas) are being depleted because of high use, mining restrictions, environmental protection regulations, and appreciating land values.

Conservation of binders is another important advantage afforded by recycling. For example, if asphalt concrete is pulverized and reused, only about one to three percent new asphalt is added, whereas a new asphalt concrete mixture must contain about six percent asphalt. This saving of about

40 liters (10 gallons) of asphalt per ton of asphaltic concrete can contribute to the national fuel conservation program because asphalt can be used directly as fuel for electrical power plants and for utilities located at refineries, or it can be converted to other hydrocarbons for use in aircraft, automobile, and steel manufacturing.

The value of recycling to energy conservation is evident if one considers the potential reduction in the hauling of aggregates and in hauling and production energy expended for the binder. However, each job must be analyzed to determine how much energy will be saved by recycling.

Recycling contributes to environmental preservation by reducing the amount of new materials required for highway use. Thus, the environmental problems inherent in mining and processing new materials are reduced, and the problems associated with the disposition of old pavement are minimized.

Pavement geometrics can be maintained by pavement recycling. On multilane roadway facilities, wide runways, taxiways, and aprons, only distressed areas need be recycled. Full-width overlays are not required for safety or drainage. Vertical control problems with drainage facilities, such as flow lines, inlet capacity, and manholes, are reduced when recycling, rather than overlay, is used.

The benefits mentioned above are of major importance to all pavement engineers. Engineers responsible for the rehabilitation and maintenance of military facilities should also consider other advantages offered by recycling, which may be of equal or greater importance. In the event of a national emergency, for example, it may be necessary to rapidly upgrade or rehabilitate airfield pavements that have been abandoned or little used since World War II. Pavement recycling is a rehabilitation option that can provide the required pavements (runways, taxiways, aprons, roadways, etc.) in a short time with the use of small amounts of additional aggregates and binders and with minimal equipment. Thus, the logistical problems associated with supplying binders, aggregates, and equipment to these often remote facilities will be greatly reduced.

Because the benefits of recycling appear promising from a number of viewpoints, several agencies, including the National Cooperative Highway Research Program (NCHRP), have sponsored research. NCHRP Synthesis 54 (Reference 5) was the first comprehensive summary of recycling information that NCHRP Study 1-17 produced (Reference 6). Federal Highway Administration-sponsored programs include: Demonstration Project No. 39, *Recycling Asphalt Pavement* (References 7 and 8); Demonstration Project No. 47, *Recycling Portland Cement Concrete Pavement* (Reference 9); National Experimental and Evaluation Program (NEEP) Project No. 22 (Reference 10); Implementation Package 75-5, which includes Office of Research studies on "Softening or Rejuvenating Agents for Recycled Bituminous Binders," "Tests for Efficiency of Mixing Recycling Asphalt Pavements," "Data Bank for Recycled Bituminous Concrete Pavement," and "Materials Characterization of Recycled Bituminous Paving Mixtures" (Reference 11); and NCHRP and special state studies (References 12 and 13). Other government-sponsored studies have been performed by the Corps of Engineers (References 14 and 15) and the Navy (Reference 16).

Associations and institutes contributing to the collection and distribution of recycling information include the American Concrete Paving Association, the Asphalt Emulsion Manufacturers Association, the Asphalt Reclaiming and Recycling Association, the Asphalt Institute,* the National Asphalt Pavement Association (References 17 and 18), the Portland Cement Association (Reference 19), and the West Coast User-Producer Group.** In addition, conferences and symposiums on pavement recycling have been held by the Transportation Research Board (Reference 20), the American Society for Testing and Materials (Reference 21), and the Association of Asphalt Paving Technologists (Reference 22).

Asphalt Pavement Recycling Using Salvaged Materials, report in preparation, Asphalt Institute, West Coast Division, Los Angeles, California.

**Miscellaneous internal reports of the Asphalt Specifications Committee, 1978, 1979.

PURPOSE AND SCOPE

The purpose of this report is to provide a comprehensive review of the state of the art of asphalt pavement recycling. The review is based on a survey of pertinent literature, interviews with established experts in the pavement field, and comments drawn from symposiums and seminars on pavement recycling. The report also includes a comprehensive plan for research on pavement recycling.

SECTION II
DEFINITIONS

Pavement recycling approaches are usually categorized according to (1) the recycling procedure used, (2) the type of paving materials to be recycled and their end products, or (3) the structural benefit to be gained from recycling (Reference 5). In this report, a categorization based on recycling procedures is used. Figure 1 shows the framework for this classification.

Various agencies and associations have developed definitions for the recycling categories. These organizations include the Federal Highway Administration Project No. 39 Technical Advisory Committee (Reference 7), a joint National Asphalt Pavement Association-Asphalt Institute committee (Reference 23), the NCHRP (Reference 6), the U.S. Army Engineer Waterways Experiment Station (References 14 and 15), and the Navy Civil Engineering Laboratory (Reference 16).

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

The following definitions are based on suggestions made by the groups mentioned above and are being used by the NCHRP (References 5 and 6).

1. Surface Recycling--Reworking of the surface of the pavement to a depth of less than about 25 millimeters (1 inch) by heater-planer, heater-scarifier, hot milling, cold planing, or cold milling devices. This operation is a continuous, single-pass, multistep process that may involve the use of new materials including aggregate, modifiers, or mixtures.

2. In-Place Surface and Base Recycling--In-place pulverization to a depth greater than about 25 millimeters (1 inch) followed by reshaping and compaction. This operation may be performed with or without the addition of a stabilizer.

3. Central Plant Recycling--Scarification of the pavement material, removal of the pavement from the roadway prior to or after pulverization, processing of material with or without the addition of a stabilizer or modifier, and laydown and compaction to desired grade. This operation may involve the addition of heat, depending on the type of material recycled and the stabilizer used.

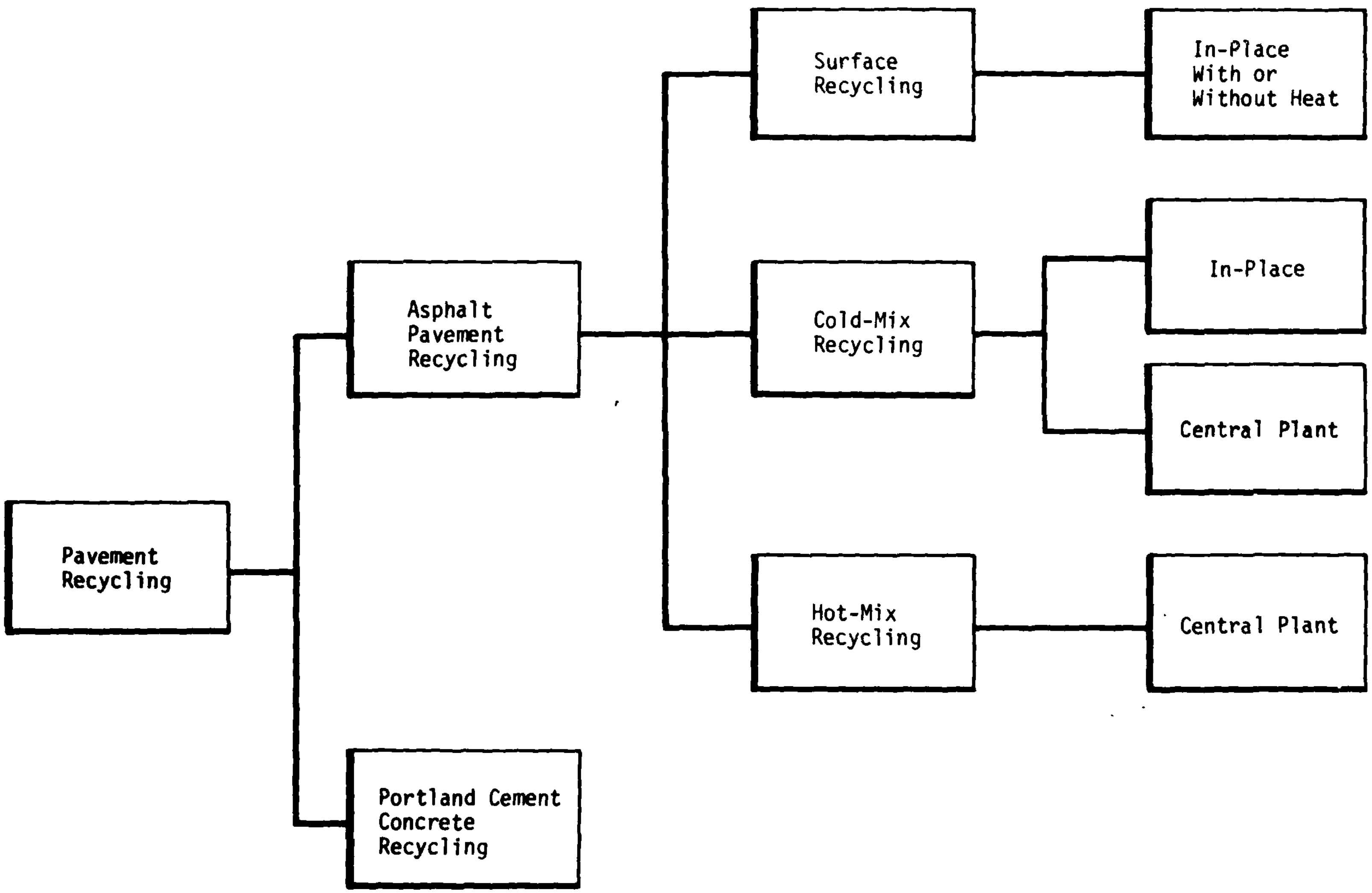

Figure 1. Categorization of Recycling Approaches on Basis of Recycling Procedures

FEDERAL HIGHWAY ADMINISTRATION

Definitions currently used by the Federal Highway Administration (FHWA) are based in part on those developed by the Joint National Asphalt Pavement Association-Asphalt Institute Committee (Reference 23). These definitions, which are given below, are used as a basis for the organization of this report.

1. Asphalt Pavement Surface Recycling--One of several methods for planing, milling, or heating in place the surface of an existing asphalt pavement. In the latter case, the pavement may be scarified, remixed, relaid, and rolled. In addition, asphalts, softening agents, minimal amounts of new asphalt hot mix, aggregates, or combinations of these may be added to obtain desirable mixture and surface characteristics. The finished product may be used as the final surface or may, in some instances, be overlaid with an asphalt surface course.

2. Cold-Mix Asphalt Pavement Recycling--One of several methods by which the entire existing pavement structure, sometimes including the underlying untreated base material, is either processed in place or removed and processed at a central plant. The materials are mixed cold and can be reused as an aggregate base; asphalt or other materials can be added during mixing to provide a stronger base. This process requires that an asphalt surface course or surface sealcoat be used.

3. Hot-Mix Asphalt Pavement Recycling--One of several methods by which the major portion of the existing pavement structure, sometimes including the underlying untreated base material, is removed, sized, and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate or a softening agent, or both. The finished product is a hot-mix asphalt base, binder, or surface course.

4. Portland Cement Concrete Pavement Recycling--A process by which an existing portland cement concrete (PCC) pavement is processed into aggregate and sand sizes and is then used in place of a new mixture; in some instances, conventional aggregates and sand are added to the processed PCC material and the mixture is placed as a new PCC pavement. This process is a phase of the econocrete concept in that the broken concrete is considered to be a local aggregate.

A careful review of these two sets of definitions discloses that the major difference between them is in the terms associated with in-place and cold-mix asphalt pavement recycling. The FHWA definition for cold-mix recycling includes central plant operations, while the NCHRP definition for in-place recycling excludes central plant cold recycling. The major advantages and disadvantages of the recycling techniques as defined are shown in Table 1 (Reference 24). Figure 1 shows the categorization of recycling operations based on the FHWA definitions given.

Definitions associated with particular types of surface, cold-mix, and hot-mix recycling, and with certain types of recycling materials are given in the appropriate sections of this report.

TABLE 1. ADVANTAGES AND DISADVANTAGES OF VARIOUS RECYCLING TECHNIQUES

Recycling Categories	Advantages	Disadvantages
Surface	Reduces reflection cracking. Promotes bond between old pavement and thin overlay. Provides a transition between new overlay and existing gutter, bridge, pavement, etc., that is resistant to raveling (eliminates feathering). Reduces localized roughness. Treats a variety of types of pavement distress (raveling, flushing, corrugation, rutting, oxidation, faulting) at a reasonable cost. Improves skid resistance. Minimizes traffic disruption.	Limited structural improvement. Heater-scarification and heater-planing have limited effectiveness on rough pavement without multiple passes of equipment. Limited repair of severely flushed or unstable pavement. Some air quality problems. Possible damage to vegetation close to roadway. Mixtures with maximum-size aggregates greater than 1 inch cannot be treated with some equipment.
In-place	Significant structural improvements. Treats all types and degrees of pavement distress. Reflection cracking can be eliminated. Frost susceptibility may be improved. Improved ride quality.	Quality control not as good as that of central plant. Traffic disruption. Pulverization equipment repair requirement. Cost. Cannot be easily performed on PCC pavements.
Central Plant	Significant structural improvements. Good quality control. Treats all types and degrees of pavement distress. Reflection cracking can be eliminated. Improved skid resistance. Frost susceptibility may be improved. Geometrics can be more easily altered. Better control if additional binder and/or aggregates must be used. Improved ride quality.	Increased traffic disruption. Possible air-quality problems at plant site.

(Reference 24)

SECTION III
ASPHALT PAVEMENT SURFACE RECYCLING

The history of surface recycling is not well documented. Heater-planer units were probably developed in California in the 1930s.* One of these was a truck-towed heater followed by a grader. Another unit was a combined heater and planer. A third was a heater mounted on a grader; a planer blade replaced the grader blade on this unit. The first cold surface recycling machine dates from about 1936.* In this device, chisels were used to cut the pavement.

Since 1930, a wide variety of recycling equipment has been developed, and a number of new techniques have been established. In this report, surface recycling is considered in terms of the following subcategories: heater planing, heater scarification, hot milling, cold planing, and cold milling. These techniques are shown in Figure 2 (Reference 5).

HOT OPERATIONS

Surface recycling operations in which heat is used may take the form of heater scarification, heater planing, or hot milling. Figure 3 shows the procedure used for planing and scarifying. Hot milling has not been used to any great extent in the United States.

Heater Planing

This process is used mainly for the maintenance of pavement grades and cross slopes. It has also been used to remove pavement in order to reduce dead weight on bridges; to remove surface irregularities caused by instability, swelling clays, or repeated crack filling; to maintain proper clearances at overhead structures; and to remove improperly designed or constructed surface treatments.

A common procedure in pavement rehabilitation is to heat and plane a pavement surface before the overlay is placed. The process corrects rutting problems; removes roughness; and provides header cut, gutter cut, or keyway to

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*Sales information provided by Jim Jackson, Contractor, Little Rock, Arkansas.

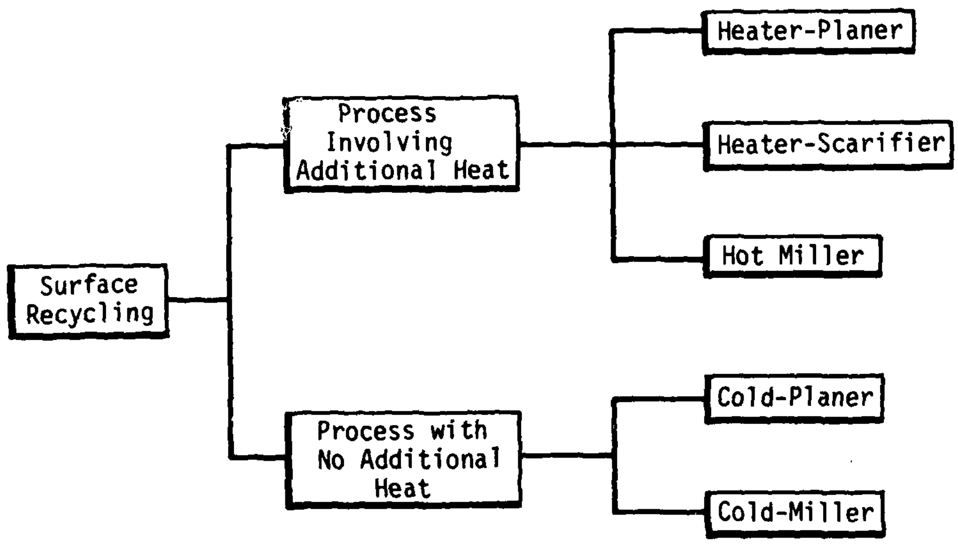


Figure 2. Surface Recycling Techniques (after Reference 5)

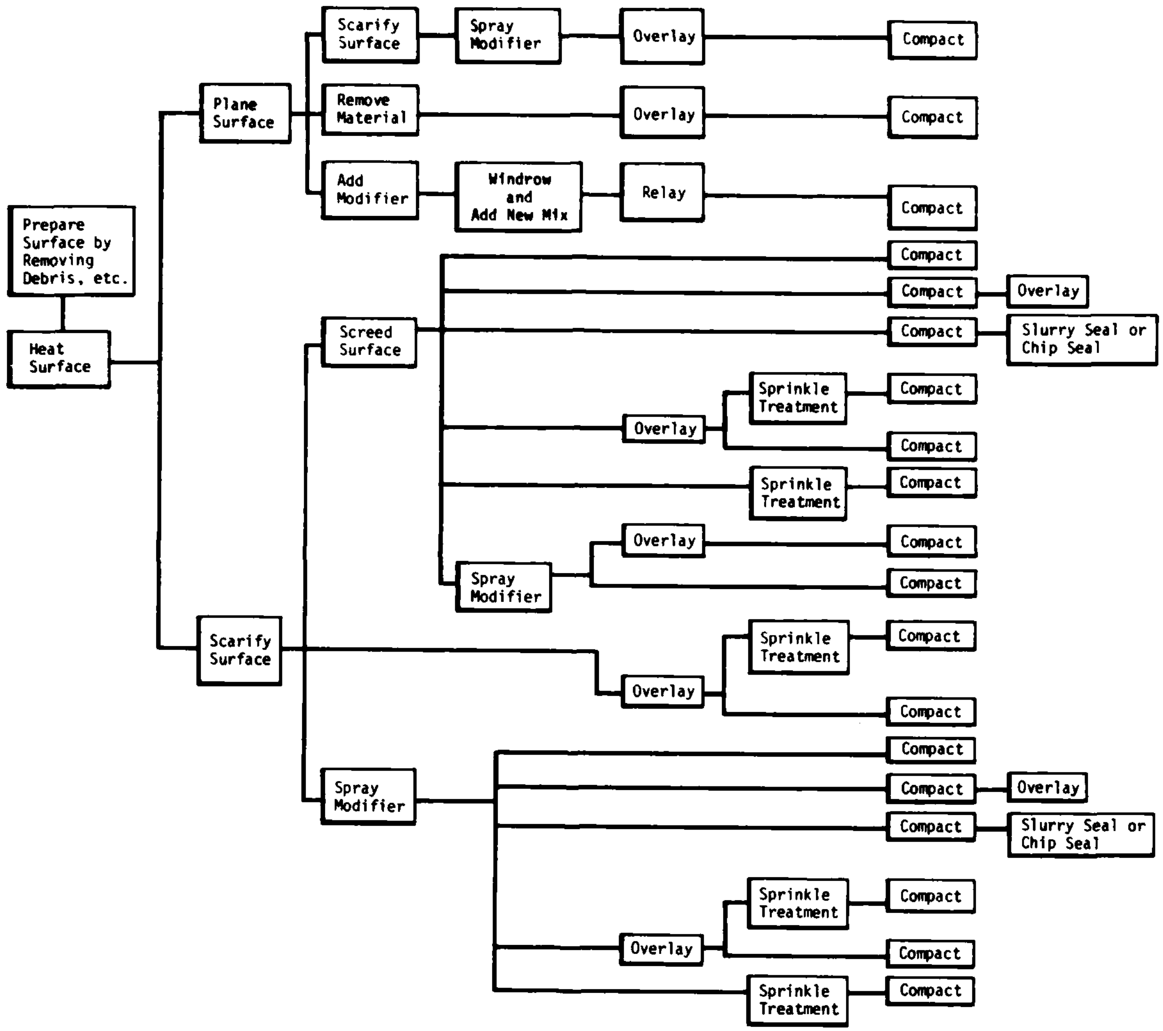


Figure 3. Planing and Scarifying Processes (after Reference 3)

prevent feathering of the hot mix. Any material removed in this process could be reused.

The heating units in heater-planers can be used in corrective maintenance projects. To improve pavements with poor skid resistance, a layer of polish-resistant aggregate is spread on the surface with a chip spreader. This is followed by an application of heat from the heater-planer. A steel wheel roller then embeds the aggregate in the old pavement. This method is effective in areas where flushing or bleeding is a problem.

Heater Scarifying

As Figure 3 shows, heater scarification takes several forms. Basically, the operations are to prepare, heat, and scarify the surface. New materials are added, if required, followed by compaction, final adjustments to manholes and drainage structures, and opening the facility to traffic.

Heater scarification has been used to remove surface irregularity and roughness. The bond between an old pavement and an asphaltic concrete overlay can be improved if a heater scarifier is used immediately prior to construction. The technique can also be used to reduce the amount of material required in the leveling courses that are placed over old pavement.

This procedure can reduce reflection cracking, which is a major factor in overlay design. Epps et al. have shown that this advantage has been experienced in the Southwest (Reference 6).

Hot Milling

As has been mentioned, this method has not been used to any great extent in the United States. Hot milling is limited to asphalt-surfaced pavements. It is used for the same purposes as cold milling, which is discussed in the following subsection.

COLD OPERATIONS

Cold Planing

This procedure is commonly used in the summer on asphalt-surfaced pavements. Cold planing is used primarily to remove corrugations and other

stability failures, to reduce rutting, and to remove improperly designed or constructed surface treatments. Local governments normally use a motor grader with hardened steel blades as a cold planer. The procedure is usually considered to be a maintenance procedure, and the material that is removed is often reused. A cold-planed pavement seldom looks or performs as well as a heater-planed pavement.

Cold Milling

This process can be used on asphalt or PCC surfaces. The main function of cold milling is to remove surface deterioration. The millings can be used as unstabilized or stabilized pavement layers. These can be treated either in place or at a central plant.

The process can be used on asphalt pavements to treat rutting, raveling, corrugations, and flushing. It may be applied to PCC to correct rutting, raveling, scaling, faulting, and spalling. The severity of the distress, among other things, determines the success of the cold milling process.

Other applications of cold milling include removing pavement roughness, improving skid resistance, and preparing the surface for overlay. Ride quality can be improved by the use of the automatic grade-control features found on many cold milling devices.

SPECIFICATIONS

Bid specifications for surface recycling are available from several sources (References 6, 25, 26, and 27). Sample specifications proposed by the Asphalt Recycling and Reclaiming Association (ARRA) (Reference 25) and by Epps et al. (Reference 6) are given in Appendix A. Those set forth by the ARRA pertain specifically to heater-scarifier operations. NCHRP report No. 224 (Reference 6) gives guide specifications that may be used to revise agency standards for any particular situation.

CASE HISTORIES

The Arizona Department of Transportation has used the heater scarification process on 39 projects in Arizona. Burgin reports that this type of

operation was useful for pavements that were structurally adequate but had surface defects such as rutting, indiscriminate patching, and flushed or sealed surfaces (Reference 28). It was projected that heater scarification would extend the life of the pavement by five years, but this figure was considered to be conservative.

In Ohio, heater scarification was used as a surface preparation for overlay on State Route 21 in Brecksville (Reference 29). It was judged that heater scarification with an application of a rejuvenating agent was more effective than a simple tack coat.

Two heater scarification projects were conducted in Texas under Demonstration Project 39 sponsored by FHWA (Reference 30). These were conducted on State Highway 336 in McAllen and on U.S. Highway 281 in Edinburg. The old pavement was scarified, winrowed, and mixed with virgin material. On these projects, recycling costs proved to be about the same as those of a conventional overlay procedure. Also, difficulties with scarification depth control were noted.

Henry reports that 46 lane-kilometers (29 lane-miles) of State Route 3 were surface recycled in Alaska (Reference 31). Heater-scarification, with an application of rejuvenator, was used to treat severe cracking and raveling. Once this surface had been treated, it was overlaid to prevent further raveling.

Surface recycling was conducted on 3.8 kilometers (2.4 miles) of six-lane U.S. Highway 41 in Fort Myers, Florida (Reference 32). The pavement surface was reworked, an emulsion prime coat was applied, and a friction course was placed. It is reported that rutting and cracking were eliminated and that the rideability of the road was improved. An estimated 25-percent savings over the cost of a conventional overlay was realized.

Webb et al. report that 18 kilometers (11 miles) of U.S. Highway 61 south of Natchez, Mississippi, were surface-recycled (Reference 33). Surface cracking and rutting were corrected by heating, scarifying, remixing, relaying, and

compacting the existing pavement. Some rutting is reported to have occurred after the facility was reopened to traffic. The cost of the recycling project was approximately 29 percent less than the cost of overlaying the pavement would have been.

In North Dakota, 80 lane-kilometers (50 lane-miles) of U.S. Highway 281, from Edgeley to Ellendale, were cold-milled (Reference 34). The objectives here were to reduce rutting, improve skid resistance, and ease the transition from the driving lane to the shoulder. Because this road had initially been overdesigned for the traffic, the removal of material from the surface did not cause the pavement to become structurally deficient. A significant savings over the cost of possible overlay options was reported.

The experiences mentioned here are by no means the only ones on record. Other case histories are available from the FHWA, the Transportation Research Board (TRB), and many state highway departments. Military experiences with surface recycling are cited in another section of this report.

SECTION IV
COLD-MIX ASPHALT PAVEMENT RECYCLING

By definition, cold-mix recycling involves the reuse of existing surface, base, subbase, and subgrade material. The material can be reprocessed in place, or it can be removed and processed, without heat, in a central plant. Binders such as lime, fly ash, portland cement, and asphalt can be used in the recycling process. A new wearing course is normally required after the pavement has been pulverized, mixed, and placed.

As a rehabilitation alternative, cold recycling has many strong points. Table 1 lists the major advantages and disadvantages of in-place cold recycling compared to surface and central plant operations. Foremost in the list of advantages is that this process significantly improves the load-bearing capability of the pavement without changing the horizontal and vertical geometry of the facility. In addition, cold recycling can be used to treat almost any type of pavement distress, to reduce or eliminate reflection cracking, to reduce frost susceptibility, and to improve skid resistance and ride quality (Reference 5). The equipment used in cold recycling is basically the same as that used in conventional soil or aggregate stabilization procedures and therefore is readily available.

Cold-mix recycling does have disadvantages. Quality control on in-place cold recycling is not as good as that available at a central plant. Further, pulverization of PCC pavements can be difficult, proper curing conditions are not easily attained, and cost and traffic disruption may be excessive (Reference 5).

IN-PLACE OPERATIONS

Figure 4 (Reference 24) shows alternatives for in-place pavement recycling without heat. Stabilizers such as lime, cement, asphalt, and various chemicals have been used in these processes. The use of cement as a stabilizer for recycled base and surface courses dates back to 1942 (Reference 35). Asphalt as a stabilizer probably dates back to the early 1940s, although

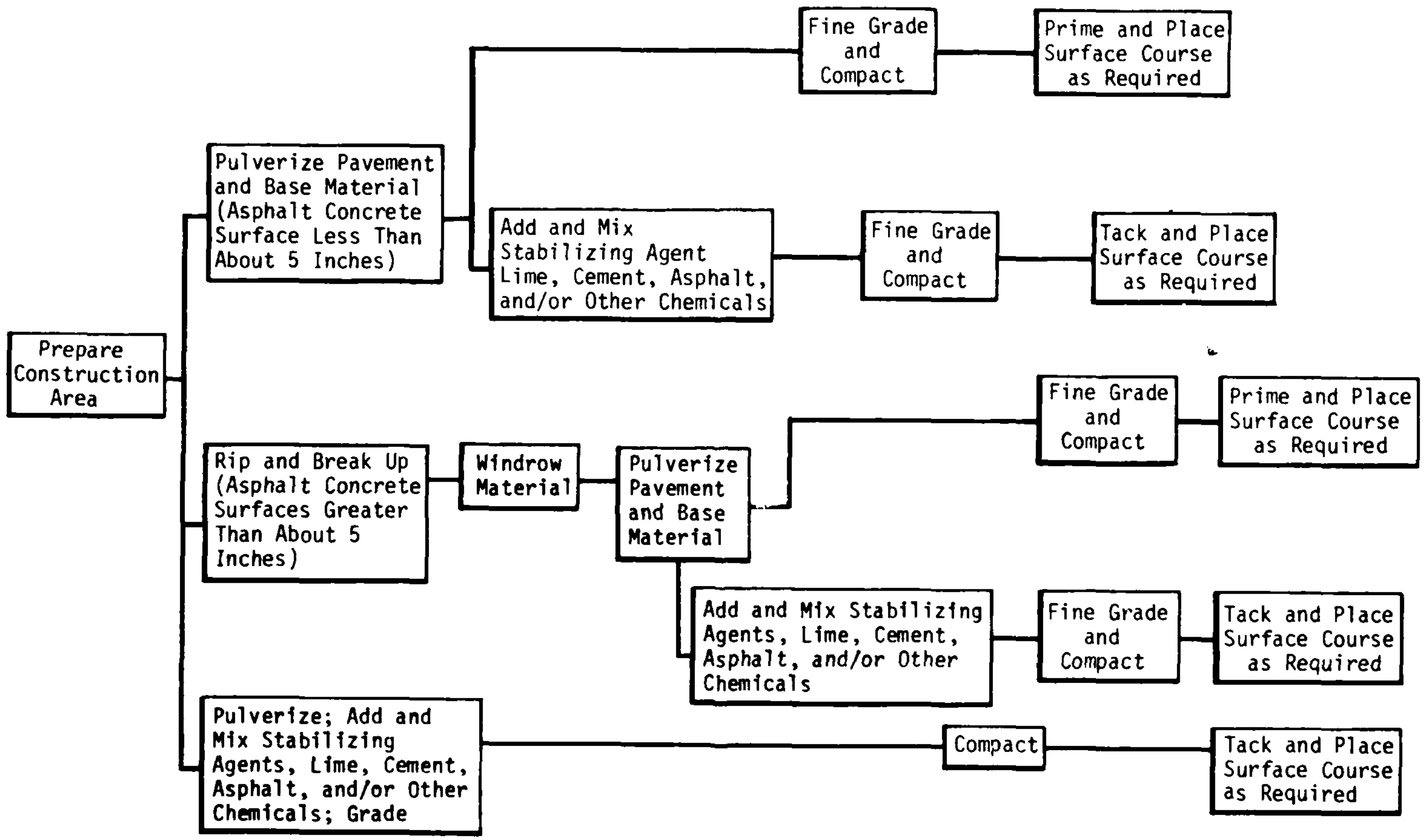


Figure 4. In-Place Cold-Mix Recycling (after Reference 24)

recent works indicate that it was first used in 1966 (Reference 36). States that have performed in-place recycling with stabilizers include Arkansas, California, Florida, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maine, Michigan, Nebraska, Nevada, New Jersey, New York, Pennsylvania, Tennessee, Texas, and Washington. It is probable that all the states have used cold recycling of pavements in-place without the addition of stabilizers (Reference 24).

As Figure 4 shows, techniques vary according to the thickness of the surface course (stabilized material). Pulverization can be performed without ripping and breaking when the stabilized layer is 50 millimeters (2 inches) thick or less. Thicknesses of greater than 50 millimeters (2 inches) can be pulverized economically with special equipment. Cold milling machines and specially altered soil stabilization equipment can pulverize economically to depths of from 130 to 180 millimeters (5 to 7 inches) (Reference 24).

The second separation of in-place recycling techniques is based on the type of stabilizing agent used. The stabilizer can be asphalt, lime, cement, or fly ash in combination with lime or cement (Reference 24).

Recently developed machines make it possible to pulverize, add and mix stabilizers, and grade the surface with a single machine operation. The widespread use of these machines will reduce costs and traffic disruptions (Reference 24).

Any number of construction sequences can be used for cold in-place recycling (Reference 24). Whatever sequence is used, the major operations include

1. Pulverization,
2. Adding and mixing stabilizers or water,
3. Fine grading,
4. Compaction, and
5. Curing.

The equipment used in performing these operations is discussed in another section of this report.

CENTRAL PLANT OPERATIONS

Central plant cold recycling techniques are similar to in-place operations. Pulverization of the material to be recycled can take place on-grade as part of the pavement removal, on-grade after initial ripping and breaking, or at the central plant after the initial ripping and breaking has been performed on-grade. Figure 5 (Reference 24) shows typical cold central plant operations.

Mixing operations at a central plant give the best opportunity to achieve uniform mixtures and can come close to achieving a 100-percent mixing efficiency. A batch plant seems to be better suited than a continuous plant to cold mix operations because it provides better uniformity and control. However, continuous plants are preferred because of their high production capability (Reference 24).

EQUIPMENT

As was mentioned previously, the equipment used for in-place recycling is similar to that used for in situ stabilization with lime, cement, and asphalt. The only special equipment required is that needed to properly size the bound material prior to stabilization (Reference 24).

A complete list of soil stabilization construction equipment identified with various stabilizers may be found in Reference 37. General summaries of soil stabilization construction equipment and operations are given in References 38 and 39 for lime, References 40 and 41 for lime fly ash, Reference 42 for cement, and Reference 43 for asphalt. The economics of cold recycling have been greatly improved through the development of pulverization and pavement removal equipment. A discussion of this equipment is presented in Reference 44.

SPECIFICATIONS

Many states have drawn up specifications for cold recycling. Those for Maine (Reference 45) and Wisconsin (Reference 7) may be found in Appendix B.

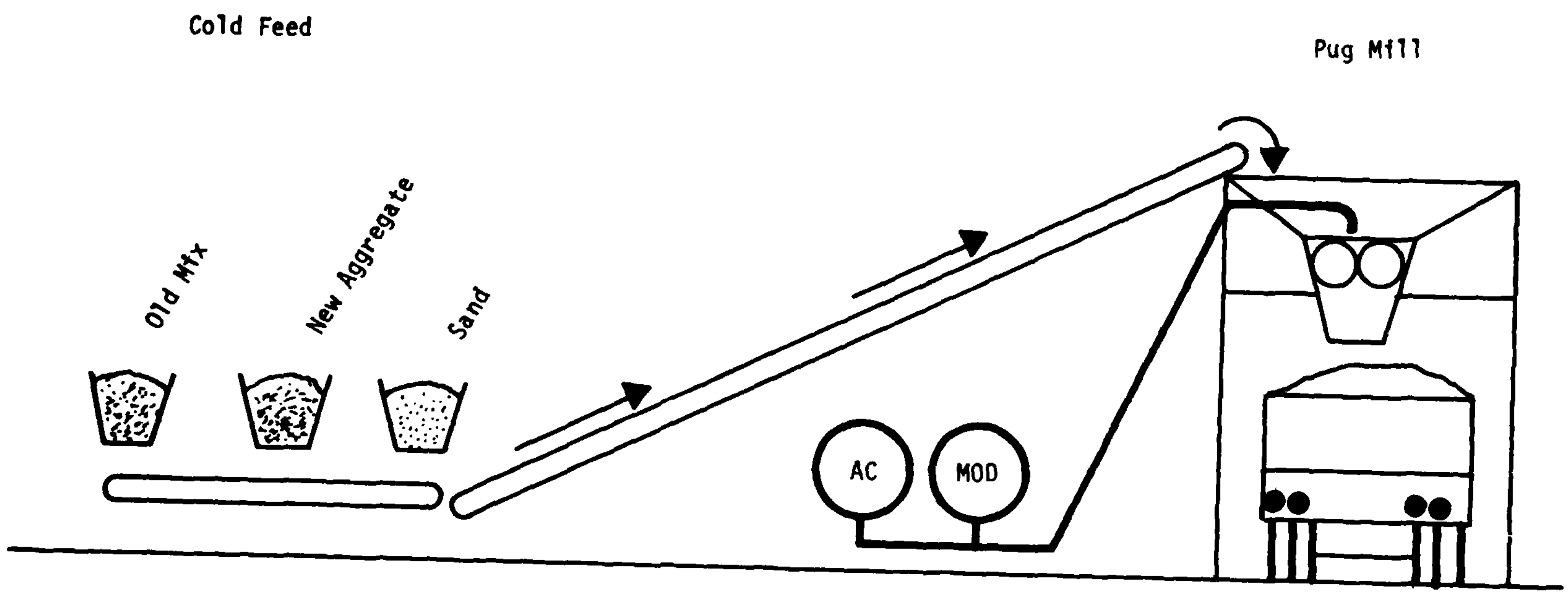


Figure 5. Central Plant Cold-Mix Recycling (after Reference 24)

Maine's specifications do not require the use of a stabilizing agent, whereas Wisconsin's call for the use of an asphalt emulsion. Appendix B also presents guide specifications proposed by Epps et al. for in-place recycling with lime, cement, and asphalt stabilizers and without chemical stabilization (Reference 6).

CASE HISTORIES

A cold recycling project conducted in Taylor County, Texas, is discussed in Reference 46. The purpose of this project was to develop a procedure in which the existing pavement would be crushed in place and asphalt and a softening agent would be added. This was considered a successful project. It was noted that the recycled material should be covered with a wearing course to prevent raveling.

Another project, constructed in Shackleford County, Texas, is reported in Reference 47. Here an asphalt emulsion was used as a stabilizing agent. The success of this project led District Eight of the Texas State Department of Highways and Public Transportation to consider in-place cold recycling on all its future farm-to-market road rehabilitation projects.

In Reference 48, Smith reports on an in-place recycling project on 6.4 lane-kilometers (4 lane-miles) of FAS Route 568 in Republic County, Kansas. An asphalt emulsion and an asphalt cutback were used as stabilizers on separate portions of the project. An asphalt chip seal was applied to the surface of the recycled material. It was concluded that this project had produced a stable surface that would be adequate for the projected traffic if a 25-millimeter (1-inch) overlay were added in 1982 or 1983.

In Jackson County, Missouri, 3.5 kilometers (2.2 miles) of a road were cold recycled (Reference 49). The recycled material was stabilized with an asphalt emulsion. Virgin aggregate was also added to improve the stability. A chip seal was applied to the surface. Phillips (Reference 49) estimates that the project saved nearly 30 percent over the cost of new hot mix.

A recycling project conducted in Sherburne, Vermont, involved 4.8 lane-kilometers (three lane-miles) of U.S. Highway 4 (Reference 50). In this project an asphalt emulsion was added to the crushed material to produce a stabilized base. Compared to Vermont's normal maintenance-rehabilitation procedure, this project cost about \$7.18 per meter^2 (\$6.00 per yard^2) more and consumed about twice the energy. These figures seem to be out of line with those reported for the majority of cold recycling projects.

This brief summary is not a complete review of all cold recycling projects to date. If the reader is interested in more case histories, reference may be made to publications of FHWA, TRB, and various state highway departments.

SECTION V
HOT-MIX ASPHALT PAVEMENT RECYCLING

As has been mentioned, hot-mix central plant recycling operations are not new. Recycling plants in which heat was used existed in 1915, and large amounts of recycled material were produced in the Pittsburg area during the 1950s and 1960s. The procedure gained a wide acceptance in 1973, when the price of asphalt cement and other construction materials increased radically. The renewed interest in central plant recycling led to the development of new techniques for heating and reusing pavement material as well as for removing and sizing the pavement. These techniques are presented in Figure 6 (Reference 6).

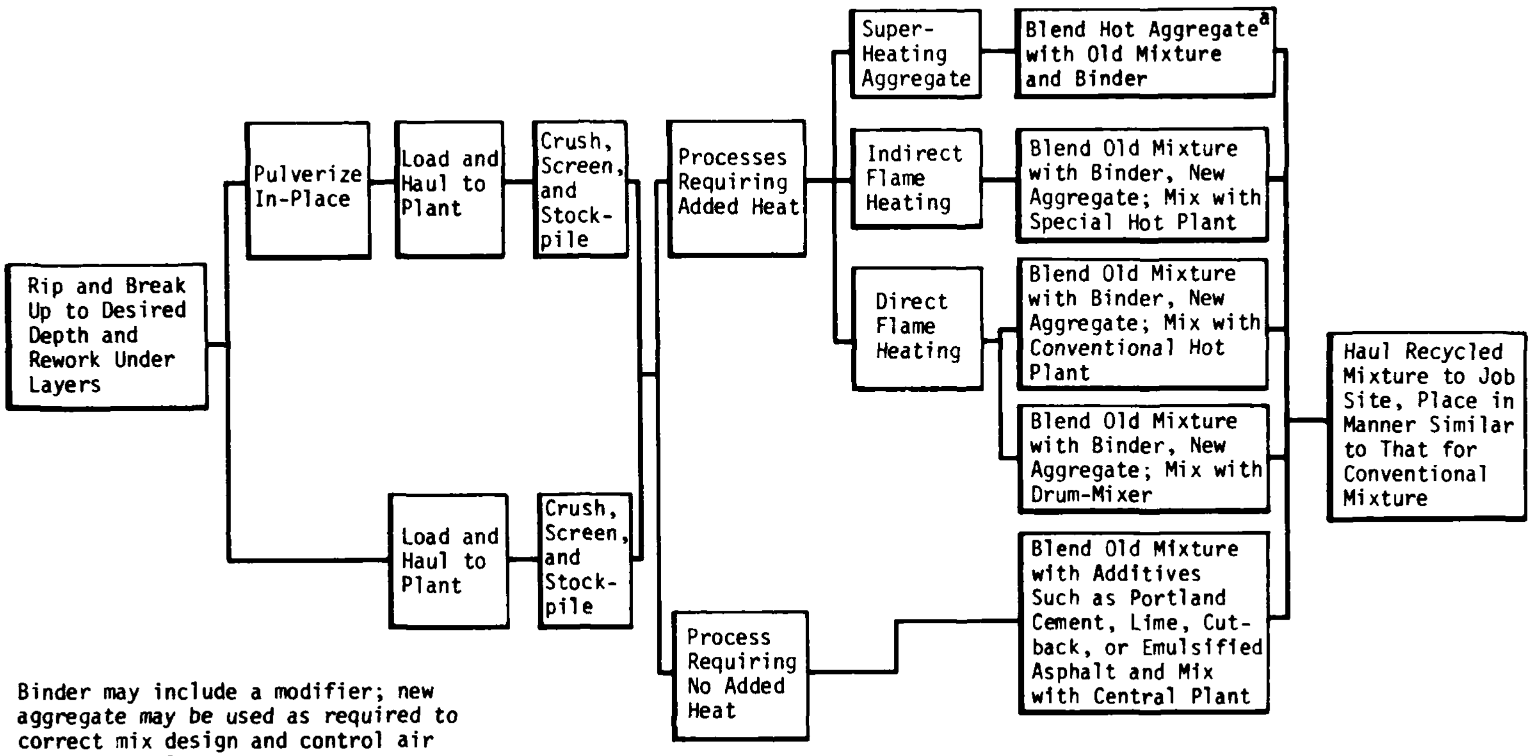
PAVEMENT REMOVAL AND SIZING

There are two approaches to sizing pavement material before it is introduced to a central plant. The material can be sized in place and hauled to the plant, or it can be removed from the site and crushed at the central plant. In-place removal and sizing can be effected with surface and in-place recycling equipment such as hot and cold milling machines, heater-planers, and on-grade pulverizers.

Sizing at a central plant can be accomplished with conventional crushing and screening equipment, which may be fixed or portable. In this process the pavement is ripped and broken, before it is loaded, to a size suitable for introduction to a primary crusher. It may be more economical to use grid rollers or other construction equipment to size the material on the site before it is transported to the central plant.

CENTRAL PLANT EQUIPMENT

Three types of central plant hot processing are used: direct flame heating, indirect flame heating, and aggregate superheating. The concepts of direct flame and aggregate superheating overlap in several of the existing processes.



a. Binder may include a modifier; new aggregate may be used as required to correct mix design and control air quality problems.

Figure 6. Central Plant Recycling Techniques (after Reference 6)

Direct flame heating is usually performed with a drum mixer. In this process all of the materials are mixed simultaneously in a revolving drum that has a flame at one end. Figure 7 (Reference 6) shows the standard drum mixer that has been used on several experimental projects. Air quality problems associated with this process have led to modifications such as the addition of heat shields and the use of split feeds.

A heat dispersion shield has been developed for use in drum mixer plants. Figure 8 (Reference 6) shows this modification. The amount of blue smoke emitted by the drum plant is reduced by the heat shield and by the injection of additional cooling air. Up to 70 percent recycled asphalt concrete can be successfully introduced in mixtures produced in this manner.

A drum within a drum plant has been used in Iowa. This concept is shown in Figure 9 (Reference 6). A small-diameter drum is inserted into the charging end of a conventional drum plant, and virgin aggregate is superheated to 150° to 260°C (300° to 500°F). The asphalt mixture to be recycled is introduced at the end of the inner drum, where heat transfer is effected. This process has been used successfully to produce mixtures containing 50 to 60 percent recycled asphalt pavement.

Figure 10 (Reference 6) shows a split-feed drum mixer plant. Virgin aggregate is fed into the flame end of the drum, where it is superheated to 150° to 260°C (300° to 500°F). The recycled material is fed into the drum at about the halfway point and is heated by a combination of hot gases and superheated aggregate. Up to about 60 percent old material can be used in this process.

Drum mixers with heat-exchanger tubes are used for indirect flame heating. This process is shown in Figure 11 (Reference 6). The heat-transfer tubes prevent the mixtures from coming into direct contact with the flame and extreme high temperatures. These plants can produce mixtures containing up to 100 percent old material.

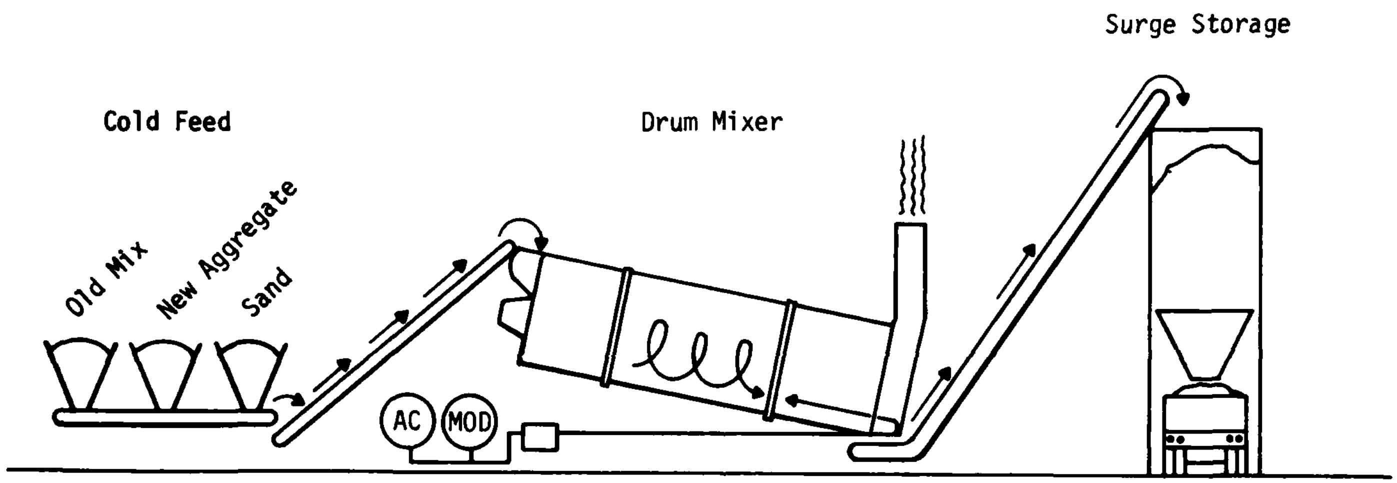


Figure 7. Standard Drum Mixer Plant (after Reference 6)

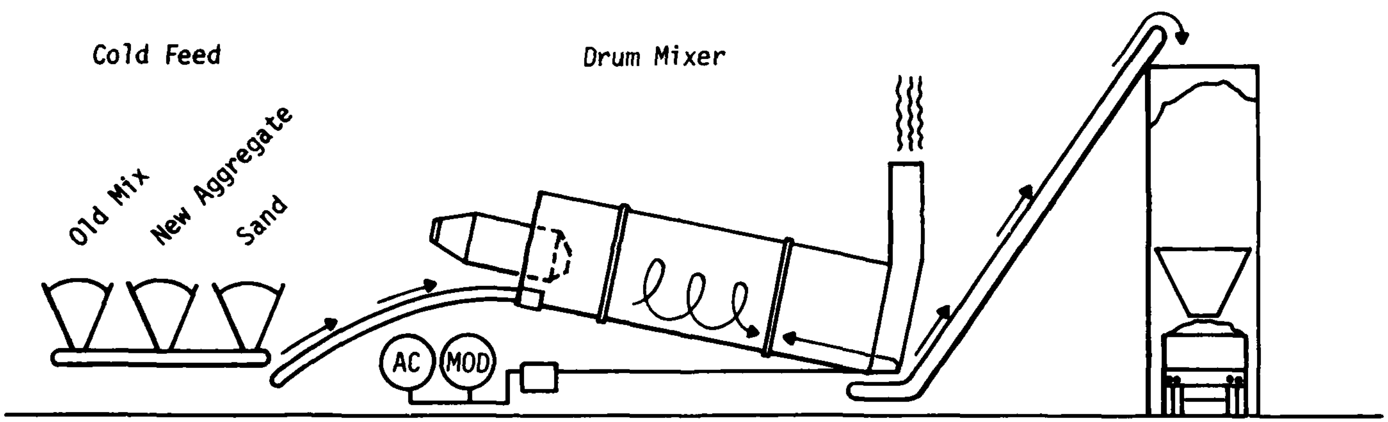


Figure 8. Drum Mixer with Heat-Dispersion Shield (after Reference 6)

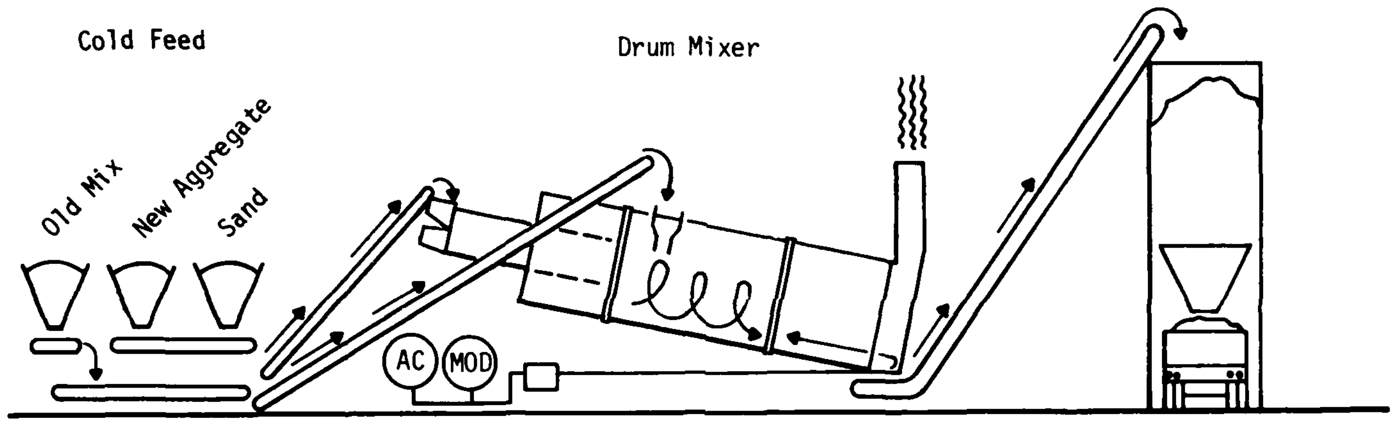


Figure 9. Drum Within Drum Plant (after Reference 6)

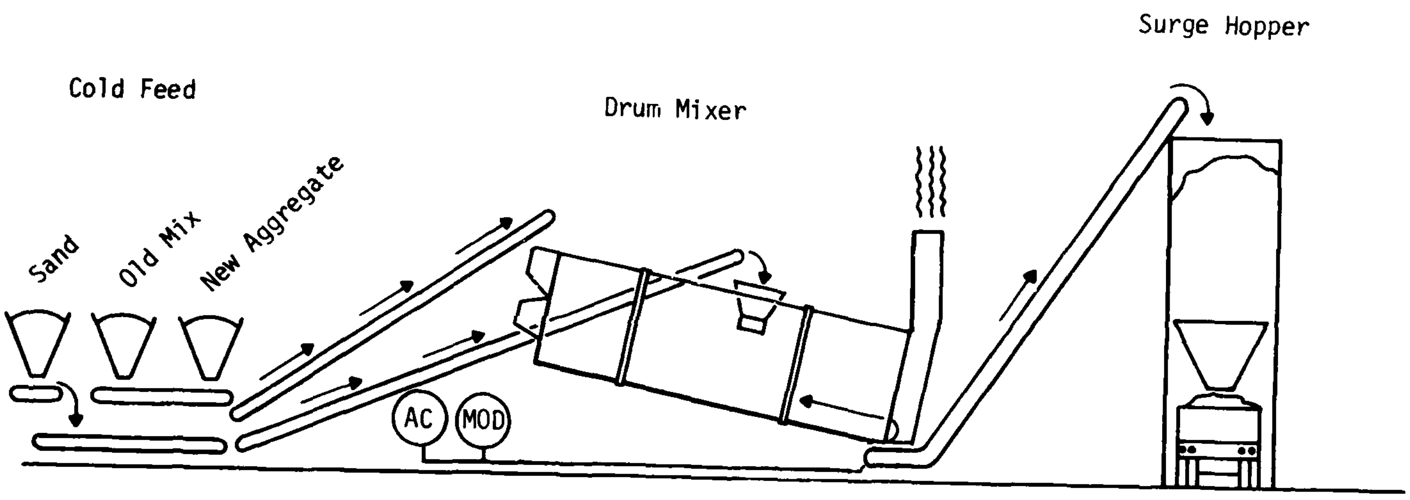


Figure 10. Split-Feed Drum Mixer (after Reference 6)

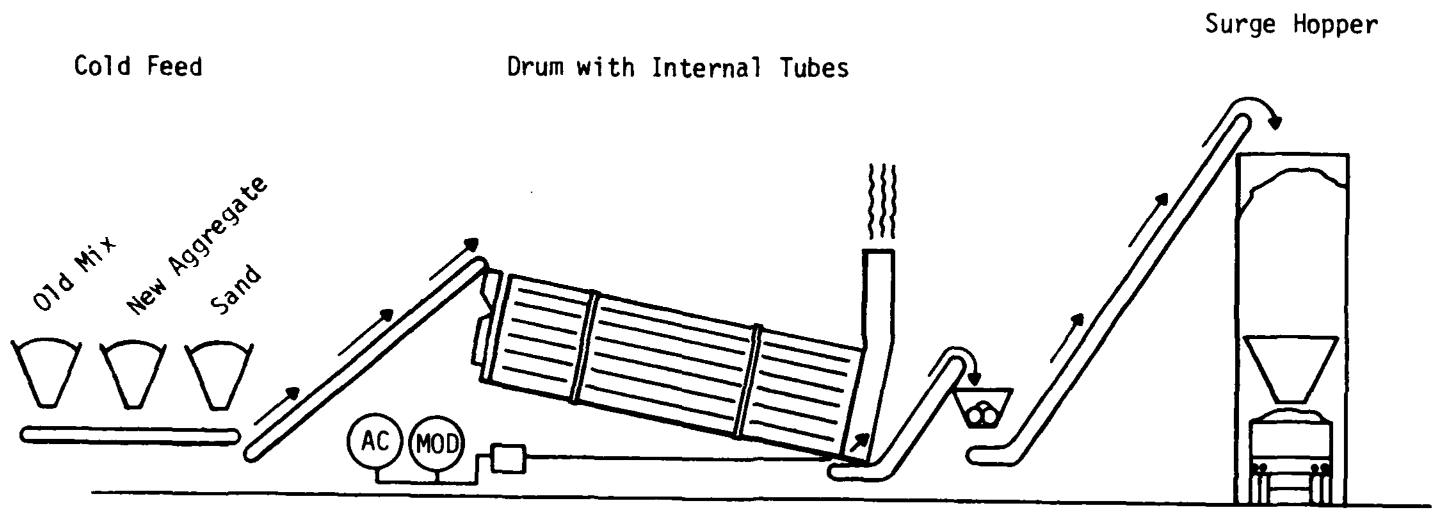


Figure 11. Drum Mixer With Heat-Exchanger Tubes (after Reference 6)

Two methods of using superheated aggregates to partially heat the old material have already been described. Figures 12, 13, and 14 (Reference 6) show three other methods by which superheated virgin aggregate is used to heat the recycled material. Figures 12 and 13 also show two methods of introducing the old pavement in a standard batch plant.

Tandem drum mixers have also been used in central plant operations (Figure 14). The first drum is an aggregate drier that superheats the aggregate. The second drum may be used either to heat the recycled material or to heat and mix the new and recycled material. The exhaust gases from the first unit may be used as the heat source for the second drum. Central plant recycling with superheated aggregate is limited to about 50-percent recycled bituminous materials.

The many advantages of central plant recycling are listed in Table 1. Quality control, with respect to particle size, recycling agent content, binder content, blending ratio of virgin and recycled aggregate, and mixture homogeneity, is easy to maintain. Near-maximum mixture strength can normally be achieved without curing. Central plant recycling can be used to repair nearly all types of pavement distress. With proper construction scheduling, a section of pavement can be removed and replaced in the same day.

SPECIFICATIONS

In NCHRP Report No. 224, Epps et al. have established guide specifications for use by various agencies (Reference 6). These specifications are given in Appendix C and are applicable to both batch and drum plants. They are not intended to be used verbatim but are to be modified for the particular project. The engineer would be expected to establish specific limits.

CASE HISTORIES

As a part of FHWA Demonstration Project 39, 39.2 kilometers (24.5 miles) of Interstate Highway 80 near Gold Run, California were hot-mix recycled (Reference 50). This was California's first attempt at hot recycling. A modified drum plant was used to produce recycled-to-virgin mixture ratios of 30/70, 40/60, and 50/50. Cost savings of about \$0.05 per meter^2 (\$0.04 per yard^2) over the cost of new mixture were realized with the 40/60 recycled mixture.

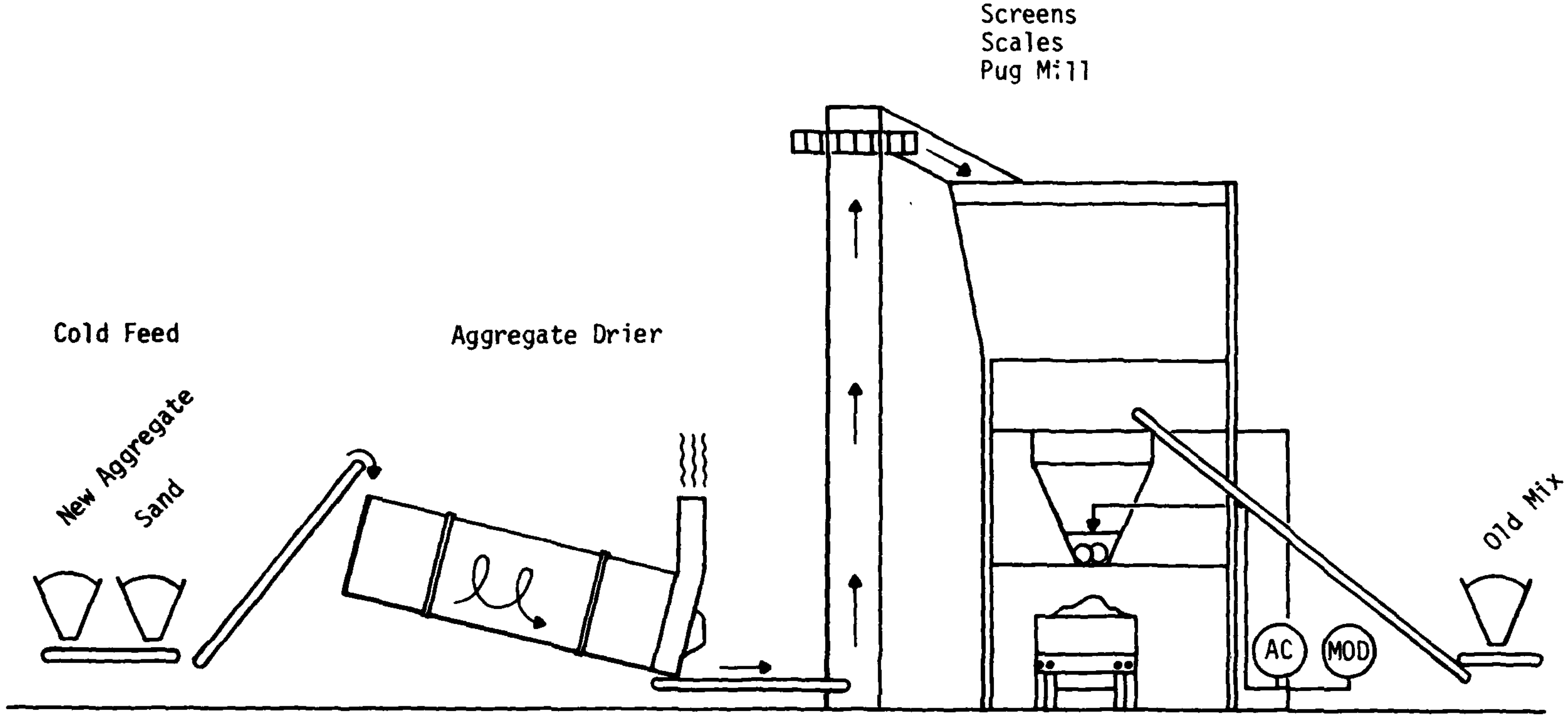


Figure 12. Batch Plant With Old Material Fed into Pug Mill (after Reference 6)

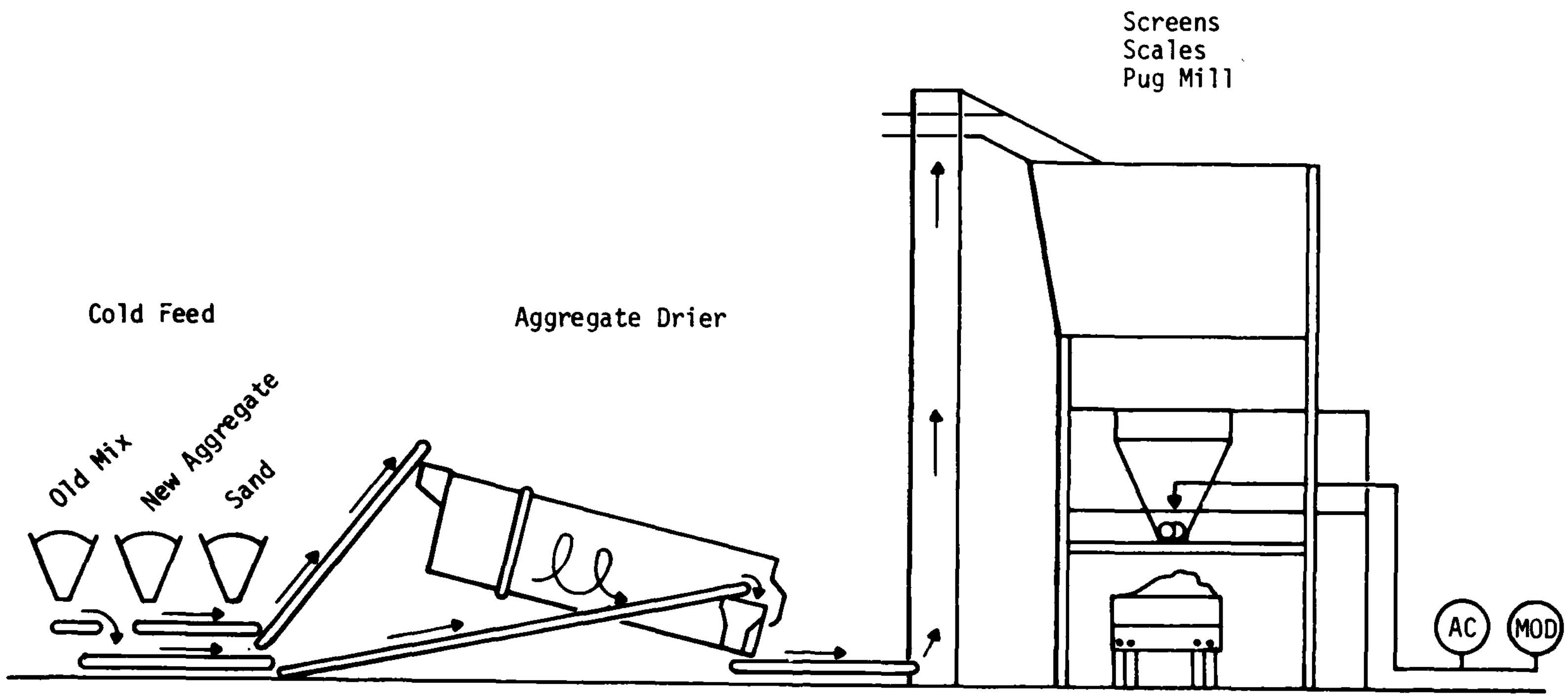


Figure 13. Batch Plant With Old Material Fed into Discharge End of Aggregate Drier (after Reference 6)

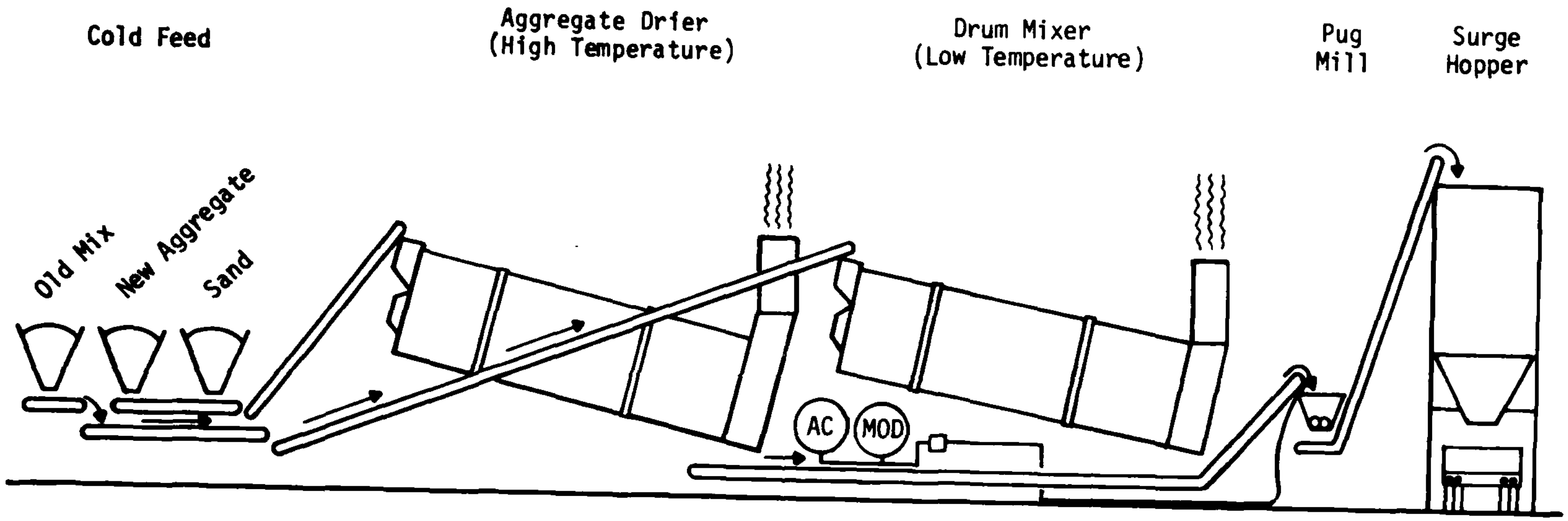


Figure 14. Tandem Drum Mixers (after Reference 6)

Overall, an estimated savings of $169,000 was realized on 39,332 tonnes (43,365 tons) of hot mix. It was noted that the skid resistance and the density of the recycled material were comparable to those of conventional mixtures.

Arizona's first hot recycling job involved 22,856 tonnes (25,200 tons) of asphalt concrete (Reference 51). This project was located between the town of Wilcox and the New Mexico state line. A drum plant was used to produce the 80/20 recycled blend. The high proportion of recycled material on this job caused pollution problems that subsequently delayed production. A net saving of $101,300 was realized on the project.

A drum plant was used for the hot recycling of five miles of Interstate 30 in Wyoming between Rawlins and Laramie (Reference 52). A cold milling machine was used to remove 113 millimeters (4.5 inches) of pavement in a single pass. This material was processed with 15 to 20 percent virgin material. Once again, the high proportion of recycled material caused pollution problems. An estimated cost savings of $3.36 per tonne ($3.05 per ton) was realized in this instance.

In Woodburn, Oregon, a temporary detour route was removed and stockpiled and was later used in a 26-lane-kilometer (16-lane-mile) reconstruction project (Reference 53). A drum plant was used to process the recycled material with 20 to 30 percent new aggregate and 0 to 2 percent AR 1000 and AR 2000 asphalt cement. It was reported that pollution control at this plant was adequate. The lack of excessive pollution was attributed to the addition of the virgin aggregate. A cost savings of 10 percent was reported, and the pavement was performing well after one year of service.

A hot-mix asphalt recycling project was constructed on 21 lane-kilometers (13 lane-miles) of U.S. Highway 98 in Panama City, Florida (Reference 54). The existing pavement was cold-planed to a depth of 25 to 88 millimeters (1 to 3.5 inches). A batch plant was used to produce a 30/70 recycled mixture. After this material had been placed and compacted, it was overlaid with a 25-millimeter (1-inch) friction course. Potts and Murphy (Reference 54) estimate that a 36-percent savings over the cost of conventional procedures was achieved in this project.

On a project in southwestern Arizona, 51 lane-kilometers (32 lane-miles) of Interstate 8 were hot-recycled (Reference 55). Recycling the existing material with a 50-millimeter (2-inch) overlay for a pavement depth of 138 millimeters (5 inches) was chosen over the option of leaving the material untreated and adding an 81-millimeter (3.25-inch) overlay for a pavement depth of 169 millimeters (6.75 inches). These were considered to be comparable strength designs. A modified drum mixer was used on this job. No cost savings were obtained, but it is believed that the structural properties were improved because cracking in the old pavement was eliminated.

In Palm Beach County, Florida, 10.2 lane-kilometers (6.5 lane-miles) of State Road 802 were hot-mix recycled (Reference 56). The cold recycled asphalt pavement was added to the hot virgin aggregate and was mixed with new asphalt cement in the pug mill of a batch plant. A 25/75 recycled-to-new material blend was produced. The saving in cost over that of a new conventional base course was 23 percent.

The Washington State Department of Transportation constructed its first recycling project on Interstate 90 between Ellensburg and the Columbia River (Reference 57). This 26-lane-kilometer (16-lane-mile) project called for 50 millimeters (2 inches) of the existing pavement to be recycled and a 19-millimeter (0.75-inch) wearing course to be placed on top. Cold milling was used to remove the existing pavement, and a batch plant was used to process the material.

In Reference 58, Moore and Welke report on the placement of a recycled surface course on a portion of State Highway M57. No major construction problems were encountered, and a high-quality wearing course was produced. However, the drum plant used on this project did not meet federal air pollution standards. The recommendation is made that existing pavements having wide variances in gradation and asphalt content not be candidate materials for use as surface courses.

In Reference 59, Ellis reviews hot recycling operations in Michigan with respect to air quality. In this study it was found that asphalt plants processing recycled material could comply with federal and state emission

standards. Ellis also states that a relationship exists between the ratio of recycled-to-new material and the resulting concentrations of particulate emissions: higher percentages of recycled material create higher particulate concentrations. The bag-house filtration system was found to be more efficient than the wet-scrubber system in removing solid particles ahead of the stack.

Again, the reader is referred to the many publications of various agencies for more case histories on hot-mix recycling.

SECTION VI
PORTLAND CEMENT CONCRETE RECYCLING

Although PCC recycling is outside the scope of this report, it is important that it be recognized briefly here as a recycling alternative. This is particularly true with respect to Air Force applications because many airfields have concrete pavements.

Pavements containing PCC have been recycled by both surface and central plant operations. Surface recycling techniques applied to concrete pavements are generally considered pavement removal operations. However, the removed pavement can be reused.

SURFACE RECYCLING

Cold milling or cold planing machines are capable of economically removing approximately 50 millimeters (2 inches) of concrete in a single pass. Traffic can operate for extended periods on the milled surface. Also, either asphalt or PCC overlays can be placed on the milled surface. The textured surface provides a measure of insurance against slippage of the overlay and makes possible the use of a thinner overlay.

The sequence of PCC surface recycling operations is as follows:

1. Establishing the desired grade line;
2. Milling, grinding, or planing the pavement to the desired depth;
3. Cleaning up, using rotary broom and vacuum equipment; and
4. Disposing of or recycling the millings.

In surface recycling operations involving overlays, this sequence of operations is used in addition to the application of a tack coat and overlay for asphaltic concrete overlays or overlay, alone, for PCC.

Milling operations are useful for correcting a variety of PCC pavement problems. These problems include rutting, severe localized surface undulations, feathered edges, poor drainage or surface texture, and low skid resistance.

Cold milling of concrete pavements with spalled joints has been partially successful. If care is taken during the milling operation, the severity of the spall can be reduced and the riding quality of the pavement improved.

CENTRAL PLANT RECYCLING

Central plant recycling of PCC dates back to World War II, when a crushed concrete pavement was used as an unstabilized base in Illinois. In 1964, a cement-treated subbase was made from crushed PCC at Love Field in Dallas, Texas. Recycled PCC was used in the first econocrete or lean concrete section, which was placed in California in 1975. The state of Iowa placed the first PCC pavement made with recycled PCC in 1976. Crushed concrete was used as aggregate for an asphalt concrete pavement in Texas in 1969. Figure 15 (Reference 6) shows the techniques used in the central plant recycling of PCC.

Pavement removal and crushing can usually be performed by conventional construction and demolition equipment. A pneumatic ram or headache ball is normally used to break up the concrete pavement. The slabs from this operation will usually be small enough to fit into the primary crusher. A further reduction in slab size can be accomplished at the crushing location. Reinforcing steel may present a rather difficult obstacle to the recycling process. It may be removed at one or more of six points:

1. On-grade during loading operations,
2. During the loading operation for crushing if stockpiling occurs prior to crushing,
3. At the entry to the primary jaw crusher,
4. On the belt after primary crushing,
5. On the belt after final crushing, or
6. In the stockpile prior to remixing.

Recycled PCC is blended and mixed at the central plant in a conventional manner. Placement and curing of the end product may also be accomplished in the standard manner. Adjustments in the gradation are often made to improve the workability of the material.

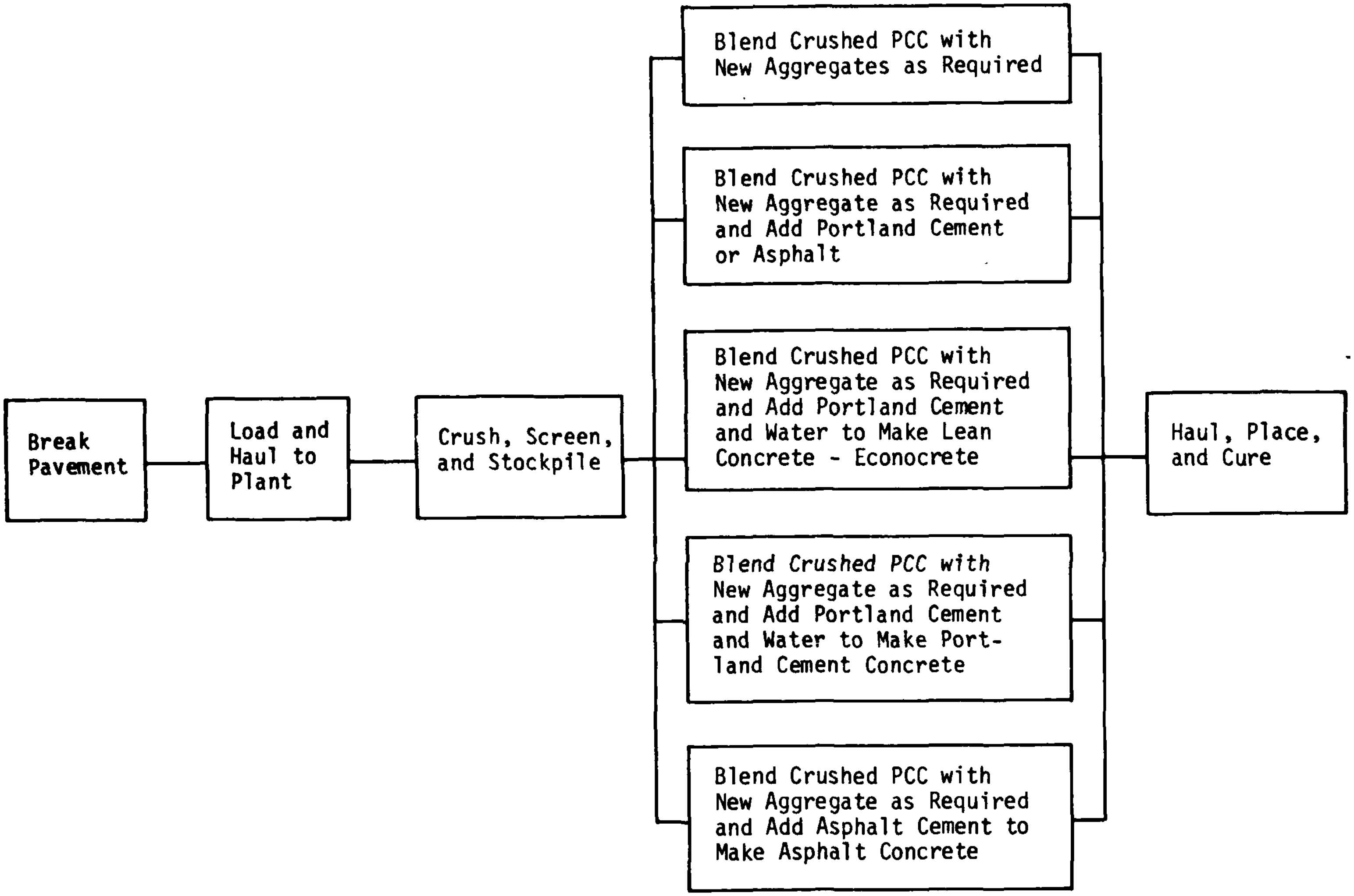


Figure 15. Central Plant Recycling Operations (after Reference 6)

The advantages of PCC pavement recycling are the same as those listed for asphalt central plant recycling (Table 1).

The use of recycled PCC as econocrete appears to be economical, especially if the crushed PCC has some contamination due to fines or asphalt-stabilized materials. This lean concrete can be placed with conventional construction equipment as the lower course in composite pavement structures. The surface course can be constructed of PCC made with natural aggregate or quality recycled aggregate with sand.

CASE HISTORIES

Reports on experiences with recycled PCC have been published by the Portland Cement Association (Reference 60), the American Concrete Paving Association (Reference 61), the Corps of Engineers (Reference 62), the NCHRP (Reference 5), and others.* In the projects described in these studies, recycled PCC was used as aggregate for econocrete, for PCC surfaces, for asphalt concrete surfaces, and for chipseals.

*Additional material on this subject was presented by G. K. Ray and H. J. Halm in "Energy Savings through Concrete Recycling," a paper presented to the Transportation Research Board, Washington, D.C., in January 1979.

SECTION VII
ADDITIVES AND MIXTURE DESIGN

ADDITIVES

In cold, hot, and surface recycling operations, chemical additives are often used to enhance the properties of the recycled materials. The selection of the type and amount of additive or stabilizer to be employed is a major concern of the engineer. The soil stabilization index system (SSIS), which was developed for the U.S. Air Force by Texas A & M University (Reference 63) and was later modified by the Air Force Academy (Reference 64) and included in an FHWA soil stabilization manual (Reference 37), has been suggested for use in designing cold recycled mixtures. The type and amount of stabilizer to be used for a given recycled material may be determined by means of this system.

Figure 16 (Reference 37) presents a stabilizer selection process based on the percent passing the 0.075-mm (No. 200) sieve and on the plasticity index (PI). On the basis of the criteria presented in Figure 16, it is evident that either lime or bituminous materials will be used in the majority of cold recycling projects involving stabilizers. A recycling agent may be needed where bituminous materials are used as additives.

After the appropriate stabilizer has been selected, design subsy-tems can be used to select the amount of stabilizer that will be required. Test methods and criteria for each type of stabilizer are briefly outlined in Reference 37.

Lime Stabilization

The design subsystem for stabilization with lime is shown in Figure 17 (Reference 37). Procedures for these tests can be found in Reference 6.

Table 2 presents the minimum residual strength criteria that must be met (Reference 65).

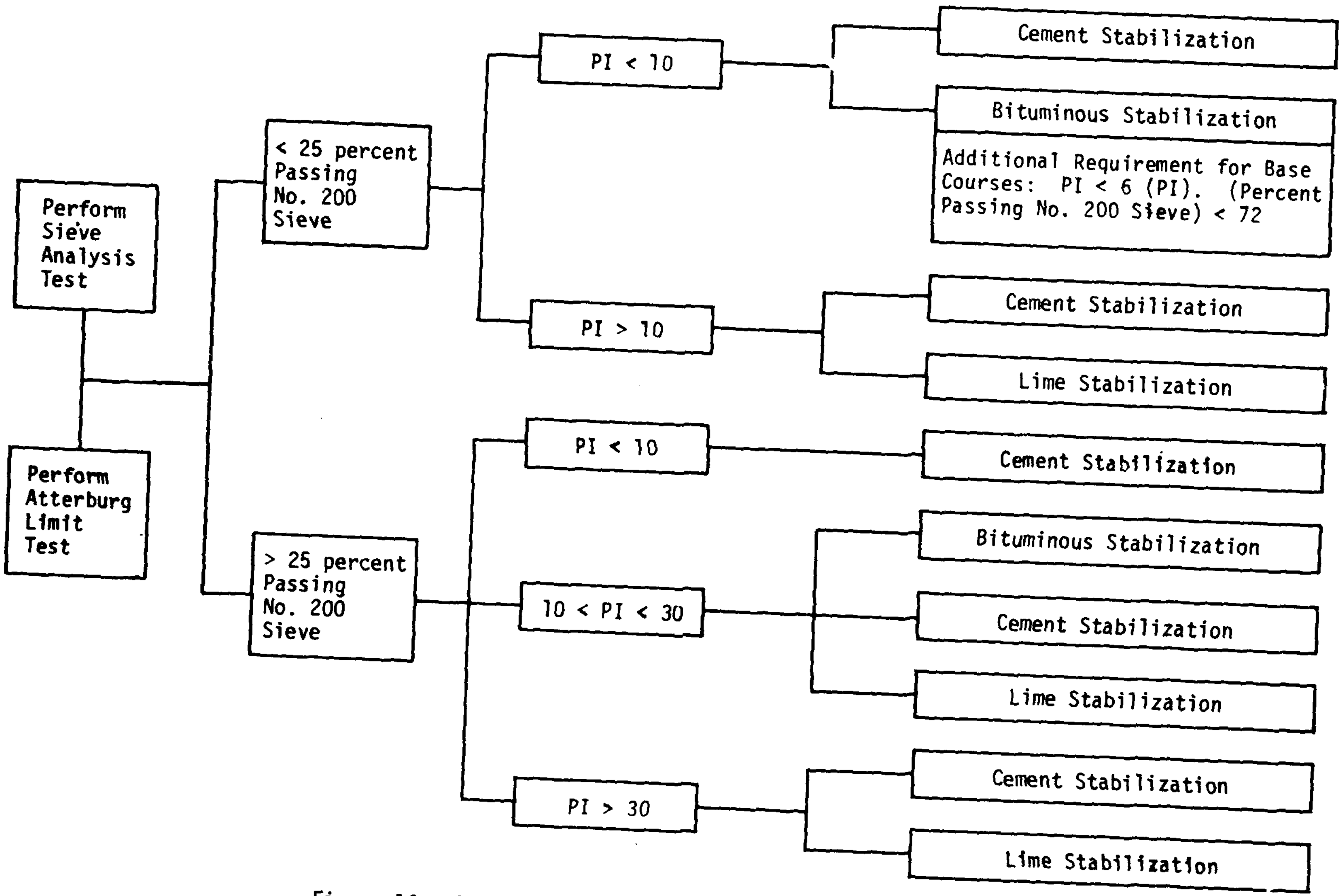


Figure 16. Selection of Stabilizer (after Reference 40)

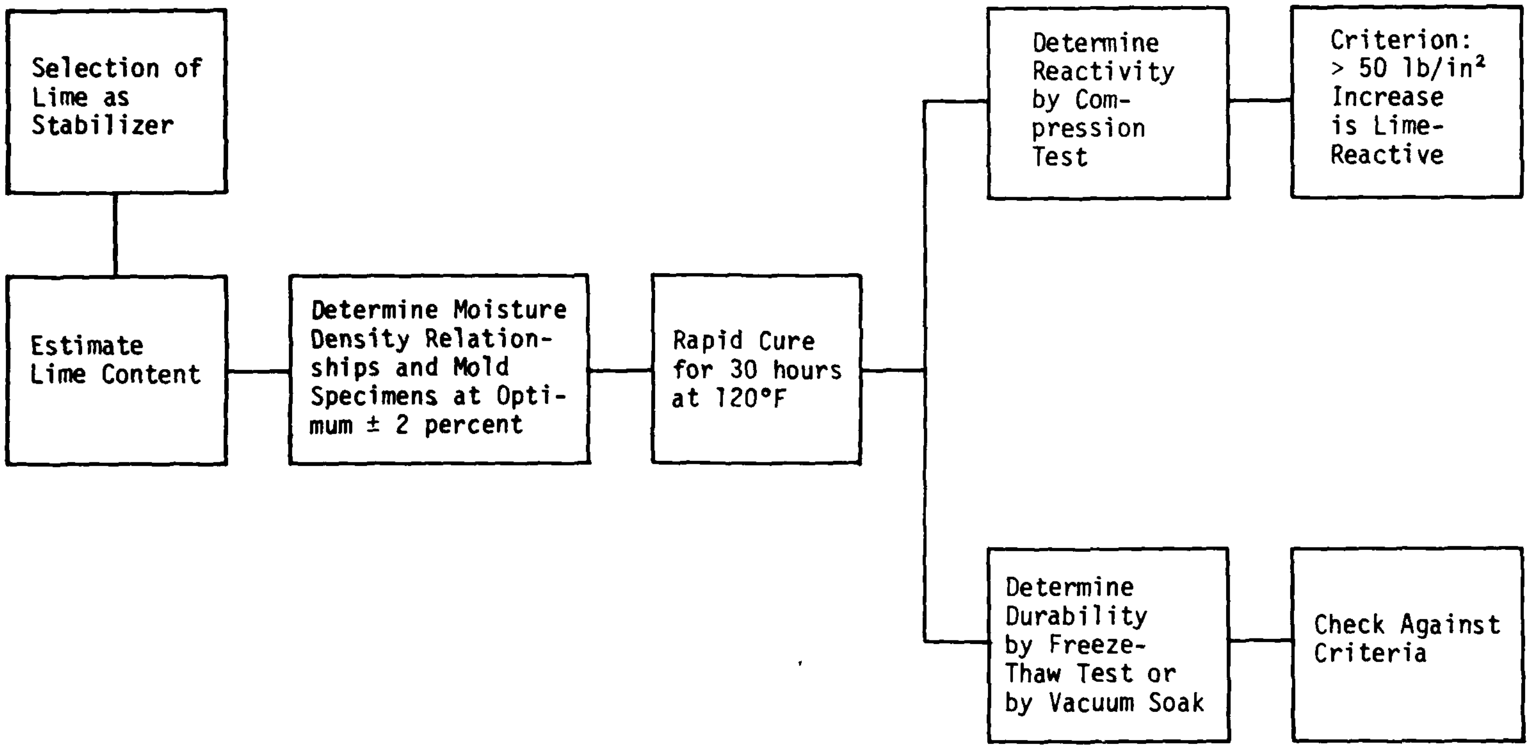


Figure 17. Design Subsystem for Lime Stabilization (after Reference 37)

TABLE 2. COMPRESSIVE STRENGTH REQUIREMENTS FOR SOIL-LIME MIXTURE

Anticipated Use	Residual Strength Requirement,	
	kPa	(lb/in^2)
Modified Subgrade	138	(20)
Subbase		
Rigid Pavement	138	(20)
Flexible Pavement	138	(20)
Cover		
10 inches thick	207	(30)
8 inches thick	276	(40)
5 inches thick	413	(60)
Base	689	(100)

(Reference 65)

Cement Stabilization

Figure 18 (Reference 37) shows the modified SSIS cement design subsystem. The only nonstandard test procedure included in this subsystem is the McLean and Sherwood pH test. An upper limit of 0.9 percent has been established for sulfate content (Reference 63). If the soil is suspected of having a high sulfate content, it should be analyzed. Reference 6 presents the turbidimetric method used to determine the amount of sulfate present. This test is warranted only if a high sulfate content is suspected.

Once the soil-cement mixture has been checked for deleterious organics, the standard Portland Cement Association (PCA) stabilization procedures can be followed (Reference 66). The wet-dry test has been found to be much less severe than the freeze-thaw test (Reference 64). Epps has suggested that only the PCA freeze-thaw weight-loss criteria be used for base course design (Reference 24). These criteria are shown in Table 3 (Reference 37).

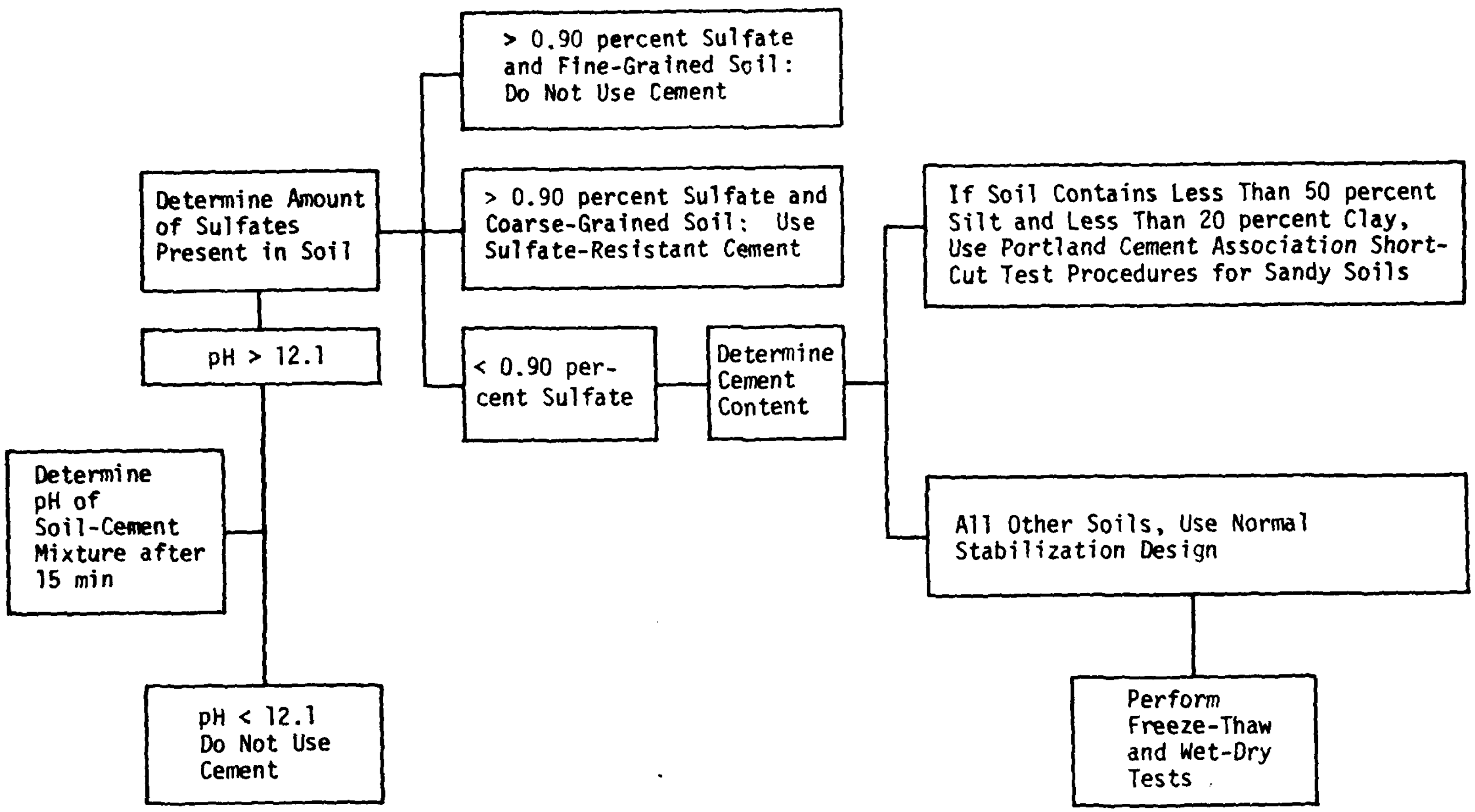


Figure 18. Design Subsystem for Portland Cement Stabilization (after Reference 37)

TABLE 3. CRITERIA FOR SOIL-CEMENT AS INDICATED BY WET-DRY AND FREEZE-THAW DURABILITY TESTS

AASHTO[a] Soil Group	Unified Soil Group	Maximum Allowable Weight Loss, Percent
A-1-a	TW, TP, GM, SW, SP, SM	14
A-1-b	GM, GP, SM, SP	[b]14
A-2	GM, GC, SM, SC	14
A-3	SP	14
A-4	CL, ML	10
A-5	ML, MH, CH	10
A-6	CL, CH	7
A-7	OH, MH, CH	7

(Reference 37)

a. American Association of State Highway and Transportation Officials.

b. Ten percent is the maximum allowable weight loss for A-2-6 and A-2-7 soils.

Note: Additional Criteria

1. Maximum volume changes during durability test should be less than 2 percent of the initial volume.
2. Maximum water content during the test should be less than the quantity required to saturate the sample at the time of molding.
3. Compressive strength should increase with age of specimen.

Asphalt Stabilization

Asphalt binders present in recycled pavements often contain physical and chemical properties that make the old asphalt undesirable for reuse unless it is modified. Vallerga and others found that the chemical changes were directly related to mixture void content and that void content is the most

important factor in asphalt hardening (Reference 67). Products have been developed and manufactured to restore these old binders to a condition that makes them suitable for reuse. A number of studies have been conducted on this subject during the past several years (References 16 and 68-73).*

Reclaiming agents have been manufactured under the names Cyclogen®, Dutrex®, Paxole®, Reclamite®, and Rejuvacote®, among others (Reference 6). Subcommittee D04.37 of the American Society for Testing and Materials (ASTM) has used the term modifier to identify these materials. The general definition of modifier is "a material that when added to asphalt cement will alter the physical-chemical properties of the resulting binder."** The West Coast User-Producer Group has developed a more specific definition for the term: recycling agent. This is a hydrocarbon product, with selected physical characteristics that will restore aged asphalt to a point at which it will meet current asphalt specifications (Reference 74). Soft asphalts, as well as specialty products, can be classified as modifiers or recycling agents.

Epps and others have reported on the use of asphalt emulsions in recycling (Reference 75). The following are the advantages of asphalt emulsions:

1. Low-temperature storage and applications
2. Construction versatility
3. Reduced energy requirements
4. Reduced air pollution
5. High mix production rates

These advantages make emulsified asphalts suitable for cold, hot, and surface recycling operations. Projects in which all three recycling categories were used have been undertaken in Texas, California, Wisconsin, Michigan, and Arizona.

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*Additional information may be found in *Asphalt Pavement Recycling Using Salvaged Materials*, preliminary report of West Coast User-Producer Group, May 1978.

**Correspondence of ASTM Subcommittee D04.37 (Modifier Agents for Bitumen in Pavements), 1977 to date.

The purpose of the recycling agent is to

1. Restore the recycled asphalt to a consistency suitable for construction purposes.

2. Restore to the recycled asphalt its optimal chemical characteristics.

3. Provide sufficient additional binder to coat any new aggregate that may be added.

4. Provide sufficient binder content to satisfy mixture design requirements.

The engineer must have a means of specifying the type and amount of modifier to be used for a particular recycling project.

Modifier specifications must be drawn up in such a way as to ensure that the modifier will perform the following functions:

1. Disperse readily in the recycled mixture (Reference 71).

2. Change the consistency of the old asphalt cement to the desired level (References 69-71).

3. Be comparable with the old asphalt so that syneresis will not occur (Reference 69).

4. Redisperse the asphaltenes in the old recycled asphalt (Reference 70).

5. Increase the life expectancy of the recycled mixture (References 69-71).

6. Produce uniform mixture properties from batch to batch (Reference 71).

7. Be resistant to smoking and flashing in hot-mix operations (References 69-71).

Tests on recycling agents, conducted during specification investigations, include those listed in Table 4.

TABLE 4. RECYCLING AGENT SPECIFICATION TESTS

Test	Specifications	Reference
Viscosity at 37.7°, 60°, 98.8°, and 135°C (100°, 140°, 210°, and 275°F)	ASTM D2170	12, 69, 70, 71
Flash Point	ASTM D92	12, 16, 69, 70, 71
Volatility	ASTM D1160	69, 72
Rolling Thin-Film Oven (RTFO) (Residue, Weight Loss, Viscosity Change, Ductility, Penetration)	AASHTO T240	70
Rostler Parameters (Compatibility, Chemical Composition)	ASTM D2006	12, 16, 69, 72
Clay-Gel Absorption Chromatography	ASTM D2077	70
Mixed Analine Point	No Nationally Accepted Specifications	12
Refractive Index	No Nationally Accepted Specifications	12
Fire Point	No Nationally Accepted Specifications	12
Smoke Point	No Nationally Accepted Specifications	12
Solubility Parameter	No Nationally Accepted Specifications	75
Specific Gravity	ASTM D70	12, 69
Viscosity-Gravity Constant	No Nationally Accepted Specifications	76
Spot Test	No Nationally Accepted Specifications	---

Epps and others have compiled a list of recycling agent research studies (Reference 77). This list includes 10 studies in which up to 37 recycling agents were investigated. Reference 12 gives the physical and chemical properties for 23 modifiers. Miscellaneous internal reports of the Asphalt Specifications Committee of the West Coast User-Producer Group* describe 33 reclaiming agents.

MIXTURE DESIGN

Various groups have proposed mixture designs for recycled materials (References 16, 24, and 78). The method proposed by Brownie and Hironaka (Reference 16) is discussed in Section X of this report. The procedures described in References 24 and 78 will be discussed here.

The method proposed by Epps is shown in Figure 19 (Reference 24). This design method allows the engineer to select the types and amounts of bituminous modifiers that will produce the desired mixture (Reference 74). The procedure is applicable to surface, cold, and hot recycling operations. The following steps are used to produce the mixture design:

1. Evaluate the materials to be recycled,
2. Determine whether additional aggregate will be needed,
3. Select the type and amount of modifier to be used,
4. Prepare and test the mixtures, and
5. Select the optimum mixture of new aggregates and modifiers.

The object of this procedure is to produce a recycled mixture that has properties approaching those of a new asphalt-concrete mixture. Standard tests have been proposed where possible. This method has been modeled after procedures suggested in References 68 through 72.

Perez and others have suggested a mixture design method in which indirect tension tests play a major role (Reference 78). In general, this design procedure consists of determining:

1. The gradation of the aggregate in the salvaged material,

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*1978, 1979.

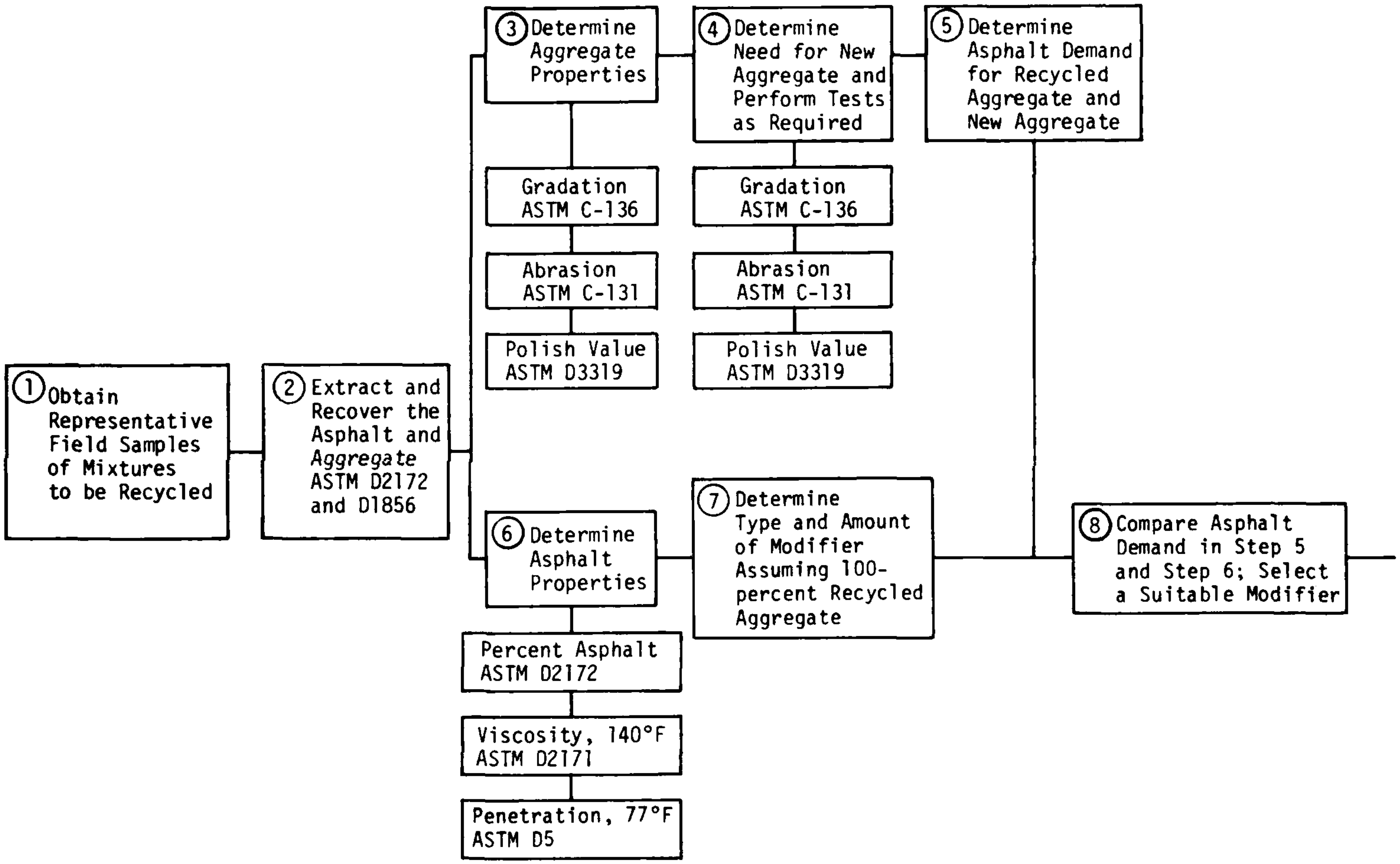

Figure 19. Mixture Design Proposed by Epps (after Reference 24)

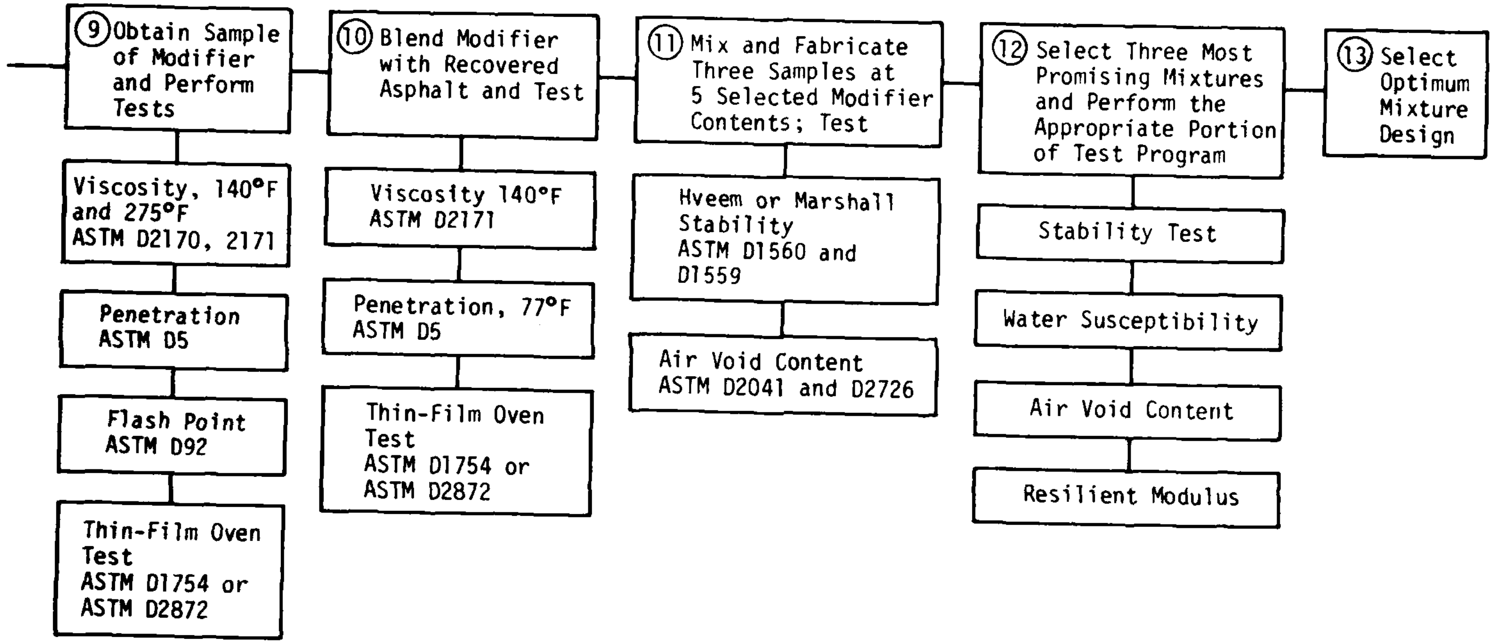

Figure 19. Mixture Design Proposed by Epps (after Reference 24) (Concluded)

2. The asphalt content in the salvaged material,

3. ꜀ final gradation after the new aggregate is added, and

4. The maximum size of the mixture particles after pulverization.

In this procedure a preliminary design is made on the basis of the binder. The procedure consists of the following steps:

1. Extracting and recovering the asphalt,

2. Mixing the recovered asphalt with various types and amounts of recycling agents,

3. Determining the consistency over a range for each additive,

4. Selecting combinations producing the desired consistency, and

5. Selecting combinations that warrant further consideration.

After the preliminary phase, Perez et al. recommend using standard mix design tests together with indirect tensile tests to determine the tensile strength, the static modulus of elasticity, the fatigue life, and the *resilient modulus of elasticity*. Table 5 (Reference 78) shows the design values proposed for indirect tensile tests.

TABLE 5. PROPOSED VALUES FOR INDIRECT TENSILE TESTS

Property	Design Value
Tensile Strength	345-965 kPa (75-200 lb/in^2)
Static Modulus of Elasticity	482,000-2,412,000 kPa (100,000-500,000 lb/in^2)
Resilient Modulus of Elasticity	1,171,000-4,479,000 kPa (250,000-900,000 lb/in^2)
Fatigue Life[a]	n_2, 2-8; K_2, 10^{11}-10^{18}

(Reference 78)

a. n_2 = material constant; the absolute value of the slope of the logarithmic relationship between fatigue life and tensile stress or stress difference.

K_2 = material constant; the antilog of the intercept value of the logarithmic relationship between fatigue life and tensile stress.

SECTION VIII
PAVEMENT DESIGN

The structural design methods currently used for recycled pavements are the same as those used for conventional pavements. Research efforts to characterize the load-carrying capability of recycled materials have not been very extensive. Most of the existing information has been produced as a result of research performed at Texas A & M University (Reference 6). These data are summarized below.

Dynaflect deflection measurements and pavement cores were obtained from 25 pavements containing recycled materials. These are shown in Table 6 (Reference 79). The data obtained were used with layered elastic computer programs and the results of the AASHTO Road Test to compute AASHTO strength coefficients and layer coefficients (stiffness equivalency). Details on the method of analysis may be found in References 6 and 79. Table 7 (Reference 79) shows AASHTO structural layer coefficients computed for recycled surface courses; Table 8 (Reference 79) contains AASHTO coefficients for base courses. Table 9 (Reference 79) presents the computed layer stiffness coefficients. Table 10 (Reference 80) contains typical AASHTO coefficients.

Material characterization parameters needed for use with the more rational pavement design methods have not, for the most part, been established. Resilient modulus data and a limited number of flexural fatigue data have been developed at Texas A & M University and at the University of Texas. Additional research is being conducted at Ohio State University.

TABLE 6. SUMMARY OF PROJECTS IN WHICH RECYCLED PAVEMENT MATERIALS WERE EVALUATED

Project	Date	Material Constructed	Recycling Process Used	Recycled Pavement Material		New Material		Additional Asphalt Modifier or Additive	
				Type	%	Type	%	Type	%
Interstate 8, Gila Bend, Arizona	1978	Surface and Base	Central, Drum Drye	Asphalt Concrete	100		0	Cyclogen L	1.20
U.S. 666, Graham County, Arizona	1977	Surface	Central, Drum Mixer	Asphalt Concrete	80	Coarse Aggregate	20	AR-2000 Extender Oil	1.40 1.40
11th Ave., Hanford, California	1976	Surface	In-place	Asphalt Road Mix	100		0	SC-800	~3.00
Russell Ave., Fresno County, California	1977	Base	In-place	Asphalt Concrete	100		0	Cyclogen H E	1.10
18th Ave., LeMoore, California	1977	Base	In-place	Asphalt Concrete	100		0	Cyclogen H E	3.50
Hwy 45, Yolo, California	1976	Base	In-place	Asphalt Concrete and Existing Base	100		0	Lime	~4.00
Elkhart, Indiana	1976	Base	In-place	Asphalt Concrete	100		0	SA-1	
Kossuth County, Iowa	1976	Surface	Central Drum Mixer	Asphalt Concrete	70	New Crushed Limestone	30	AC-10	3.50
U.S. 56, Pawnee County, Kansas	1977	Base	In-place				0		
Section 1				Asphalt Concrete	100			Cement	2.00
Section 2				Asphalt Concrete	100			Cement	1.50
Section 3				Asphalt Concrete	100			MC-800	1.00
Section 4				Asphalt Concrete	100			Cement and AC-7	1.50 1.50

TABLE 6. SUMMARY OF PROJECTS IN WHICH RECYCLED PAVEMENT MATERIALS WERE EVALUATED (CONTINUED)

Project	Date	Material Constructed	Recycling Process Used	Recycled Pavement Material		New Material		Additional Asphalt Modifier or Additive	
				Type	%	Type	%	Type	%
Interstate 69, Flint, Michigan	1976	Base for Shoulder	In-place	Existing Base	100		0	AC-200 or MC-800	
Trunk Hwy 94, Minnesota	1977	Surface and Base	Central, Thermo Drum	Asphalt Concrete Existing Base	50 50		0	AC (200-300 Pen)	2.50
Interstate 15, Henderson, Nevada	1974	Surface	Central, Drum Mixer	Asphalt Concrete	100		0	AR-8000 Paxole	1.50 0.75
U.S. 50, Dayton, Nevada	1975	Base	In-place	Asphalt Concrete and Existing Base	100		0	Cement	2.50
U.S. 93, Wells, Nevada	1975	Base	In-place	Asphalt Concrete and Existing Base	100		0	Cement	1.50
Ponderosa Ave., Inclined Village, Nevada	1975	Base	In-place	Asphalt Concrete and Existing Base	100		0	Cement	4.00
Hillsboro to Silverton Hwy, Woodburn, Oregon	1977	Surface	Central, Drum Mixer	Asphalt Concrete	70	Crushed Limestone	30	AR-2000	1.80
Interstate 20, Roscoe, Texas	1976	Base	Central, Drum Mixer	Asphalt Concrete Existing Aggregate Base	69	Crushed Limestone	15	AC-5	2.30
Hwy 36, Burleson County, Texas	1972	Surface	Central, Drum Mixer	Portland Cement Concrete	80	Sand	20	AC-10	4.80
U.S. 54, Dalhart, Texas	1972	Surface	Central, Drum Mixer	Portland Cement Concrete	100		0	AC-10	6.50

TABLE 6. SUMMARY OF PROJECTS IN WHICH RECYCLED PAVEMENT MATERIALS WERE EVALUATED (CONCLUDED)

Project	Date	Material Constructed	Recycling Process Used	Recycled Pavement Material		New Material		Additional Asphalt Modifier or Additive	
				Type	%	Type	%	Type	%
U.S. 84, Snyder, Texas	1976	Base	Central, Hot Pug Mill						
Section 1				Asphalt Concrete	80	Base	20	EA-11 M	5.00
Section 2				Asphalt Concrete	50	Base	50	EA-11 M	6.00
Section 3				Asphalt Concrete	40	Base	60	AC-10	6.00
Section 4				Asphalt Concrete	30	Base	70	AC-10	7.00
Section 5				Asphalt Concrete	100		0	AC-10	4.00
U.S. 277, Abilene, Texas	1975	Surface	In-place	Asphalt Concrete	100		0	EA-11 M Reclamite	5.00 1.00
Loop 374, Mission, Texas	1975	Surface	Central, Drum Mixer						
Section 1				Asphalt Concrete	100		0	Reclamite	1.60
Section 2				Asphalt Concrete	100		0	AC-5	3.00
Section 3				Asphalt Concrete	100		0	Flux Oil	2.00
U.S. 50, Holden, Utah	1975	Surface	Central, Drum Mixer						
Sections 7-17				Asphalt Concrete	100		0	AC-10	~1.50
Section 18				Asphalt Concrete	77	Aggregate	23	AC-10	~1.50
Section 19				Asphalt Concrete	85	Aggregate	15	Softening Agent	0.50
Blewitt Pass, Washington	1977	Surface	Central, Drum Mixer	Asphalt Concrete Millings	93	Aggregate	7	AC-5 Softening Agent	~0.50
Rye Grass, Washington	1977	Surface	Central, Drum Mixer	Asphalt Concrete Millings	72	Aggregate	28	Cyclopave	0.75

(Reference 79)

TABLE 7. AASHTO STRUCTURAL LAYER COEFFICIENTS COMPUTED FOR RECYCLED SURFACES EVALUATED

Project	Computed Structural Layer Coefficient (a_1') Based on Response Criterion		
	W_s	$\varepsilon_{ac}(N_{18})$	a_1' Selected
Interstate 8, Gila Bend, Arizona	0.44	0.46	0.44
U.S. Highway 666, Graham County, Arizona	0.46	0.49	0.46
Kossuth County, Iowa	0.43	0.46	0.43
Trunk Highway 94, Minnesota	0.42	0.42	0.42
Interstate 15, Henderson, Nevada	0.57	0.60	0.57
Hillsboro to Silverton Highway, Woodburn, Oregon	0.49	0.54	0.49
Interstate 20, Roscoe, Texas	0.44	0.44	0.44
U.S. Highway 36, Burleson County, Texas	0.54	0.65	0.54
U.S. Highway 54, Dalhart, Texas	0.43	0.44	0.43
U.S. Highway 277, Abilene, Texas	0.44	0.44	0.44
Loop 374, Mission, Texas (Section 1)	0.45	0.48	0.45
Loop 374, Mission, Texas (Section 2)	0.46	0.48	0.46
Loop 374, Mission, Texas (Section 3)	0.39	0.38	0.39
U.S. Highway 50, Holden, Utah	0.54	0.66	0.54
Blewitt Pass, Washington	0.46	0.46	0.46
Rye Grass, Washington	0.47	0.51	0.47

(Reference 79)

Notes: W_s = subgrade deformation.

N_{18} = number of 18-kip (80.1-kN) load applications to failure based on relationship between tensile strain in recycled AC layer, ε_{ac}, and N_{18}.

TABLE 8. STRUCTURAL LAYER COEFFICIENTS COMPUTED FOR RECYCLED BASES EVALUATED

Recycled Base	Description of Recycled Base	Reference Base Thickness, mm (in)	Structural Layer Coefficient of Recycled Base (a_2')
18th Avenue, LeMoore, California	Crushed AC; 3.5% Cyclogen	350 (14) 250 (10) 150 (6)	0.40 0.42 0.46
Russel Avenue, California	Crushed AC; 1.1% Cyclogen HE	350 (14) 250 (10) 150 (6)	0.36 0.40 0.42
Highway 45, Yolo, California	Crushed AC; Existing Base and Native Sub-grade Stabilized with Lime	350 (14) 250 (10) 150 (6)	0.40 0.42 0.46
U.S. Highway 56, Kansas (Section 2)	Crushed AC; 1.5% Cement and 3.8% Water	350 (14) 250 (10) 150 (6)	0.45 0.49 0.56
U.S. Highway 56, Kansas (Section 3)	Crushed AC; 1% MC-800	350 (14) 250 (10) 150 (6)	0.41 0.45 0.50
U.S. Highway 56, Kansas (Section 4)	Crushed AC; 1.5% Cement, 1.5% AC-7, and 4% Water	350 (14) 250 (10) 150 (6)	0.44 0.49 0.55
TH 94, Minnesota	Crushed AC; Existing Base; 2.5% AC	350 (14) 250 (10) 150 (6)	0.46 0.51 0.54
U.S. Highway 50, Nevada	Crushed AC; Existing Base; Cement	350 (14) 250 (10) 150 (6)	0.25 0.27 0.31
U.S. Highway 93, Nevada	Crushed AC; Existing Base; Cement	350 (14) 250 (10) 150 (6)	0.53 0.56 0.61
Ponderosa Avenue, Inclined Village, Nevada	Crushed AC; Existing Base; Cement	350 (14) 250 (10) 150 (6)	0.25 0.27 0.31
Interstate 20, Roscoe, Texas	Crushed AC; Existing Base; 2.8% AC-3	350 (14) 250 (10) 150 (6)	0.41 0.43 0.46
Russell Avenue, California	Crushed AC; 1.1% Cyclogen HE	350 (14) 250 (10) 150 (6)	0.36 0.40 0.42
U.S. Highway 84, Texas (Section 1)	Crushed AC; Base; 5% Asphalt Emulsion	350 (14) 250 (10) 150 (6)	0.52 0.56 0.62

(Reference 79)

TABLE 9. SUMMARY OF THICKNESS EQUIVALENCY RATIOS

Project Designation	Recycled Layer Analyzed	Control Section Reference Layer	Thickness Equivalency Ratio (B)
Interstate 8, Gila Bend, Arizona Section 2 Versus Section 1	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	1.02
Interstate 8, Gila Bend, Arizona Section 4 Versus Section 3	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	0.90
Interstate 8, Gila Bend, Arizona Section 5 Versus Section 6	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	1.03
Interstate 8, Gila Bend, Arizona Section 5 Versus Section 3	Recycled Asphalt Concrete (Full Depth)	Conventional Asphalt Concrete (Full Depth)	0.91
11th Avenue, Hanford, California	Recycled Asphalt Road Mix	Conventional Asphalt Road Mix	1.00
Russell Avenue, Fresno, County, California	Recycled Asphalt Stabilized Base	Conventional Road Mix Asphalt Stabilized Base	3.44
18th Avenue, LeMoore, California	Recycled Asphalt Stabilized Base	Conventional Aggregate Base	2.40
Highway 45, Yolo, California	Recycled Base Lime Stabilized	Conventional Asphalt Concrete Surface	1.24

TABLE 9. SUMMARY OF THICKNESS EQUIVALENCY RATIOS (CONTINUED)

Project Designation	Recycled Layer Analyzed	Control Section Reference Layer	Thickness Equivalency Ratio (B)
U.S. 56, Pawnee County, Kansas	Recycled Asphalt Concrete Base (Section 1)	Conventional Asphalt Concrete (Full Depth)	1.25
U.S. 56, Pawnee County, Kansas	Recycled Asphalt Concrete Base (Section 2)	Conventional Asphalt Concrete (Full Depth)	0.98
U.S. 56, Pawnee County, Kansas	Recycled Asphalt Concrete Base (Section 3)	Conventional Asphalt Concrete (Full Depth)	1.12
U.S. 56, Pawnee County, Kansas	Recycled Asphalt Concrete Base (Section 4)	Conventional Asphalt Concrete (Full Depth)	1.12
Interstate 15, Henderson, Nevada	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	0.87
U.S. 50, Dayton, Nevada	Recycled Base Cement Stabilized	Conventional Asphalt Concrete Surface	0.42
U.S. 93, Wells, Nevada	Recycled Base Cement Stabilized (Section 1)	Conventional Asphalt Concrete Surface	1.15
U.S. 93, Wells, Nevada	Recycled Base Cement Stabilized (Section 2)	Conventional Asphalt Concrete Surface	1.54
Ponderosa Avenue, Inclined Village, Nevada	Recycled Base Cement Stabilized	Conventional Asphalt Concrete Surface	0.56
Hillsboro to Silverton Highway, Woodburn, Oregon	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	0.90

TABLE 9. SUMMARY OF THICKNESS EQUIVALENCY RATIOS (CONTINUED)

Project Designation	Recycled Layer Analyzed	Control Section Reference Layer	Thickness Equivalency Ratio (B)
Interstate 20, Roscoe, Texas	Recycled Asphalt Concrete Base (Section 1)	Conventional Asphalt Concrete Surface	1.08
Interstate 20, Roscoe, Texas	Recycled Asphalt Concrete Base (Section 2)	Conventional Asphalt Concrete Surface	1.24
Interstate 20, Roscoe, Texas	Recycled Asphalt Concrete Base (Section 3)	Conventional Asphalt Concrete Surface	1.05
U.S. 54, Dalhart, Texas	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	0.98
U.S. 84, Snyder, Texas	Recycled Asphalt Concrete Base (Section 1)	Conventional Asphalt Concrete Surface	1.98
U.S. 84, Snyder, Texas	Recycled Asphalt Concrete Base (Section 2)	Conventional Asphalt Concrete Surface	1.57
U.S. 84, Snyder, Texas	Recycled Asphalt Concrete Base (Section 3)	Conventional Asphalt Concrete Surface	1.59
U.S. 84, Snyder, Texas	Recycled Asphalt Concrete Base (Section 4)	Conventional Asphalt Concrete Surface	1.59
U.S. 277, Abilene, Texas	Recycled Asphalt Concrete Base	Conventional Asphalt Concrete Surface	0.54
U.S. 50, Holden, Utah	Recycled Asphalt Concrete Surface (Sections 7-17)	Conventional Asphalt Concrete Surface (Sections 1-4)	1.40

TABLE 9. SUMMARY OF THICKNESS EQUIVALENCY RATIOS (CONCLUDED)

Project Designation	Recycled Layer Analyzed	Control Section Reference Layer	Thickness Equivalency Ratio (B)
U.S. 50, Holden, Utah	Recycled Asphalt Concrete Surface (Section 18)	Conventional Asphalt Concrete Surface (Sections 1-4)	1.59
U.S. 50, Holden, Utah	Recycled Asphalt Concrete Surface (Section 19)	Conventional Asphalt Concrete Surface (Sections 1-4)	1.54
Blewitt Pass, Washington	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	0.34
Rye Grass, Washington	Recycled Asphalt Concrete Surface	Conventional Asphalt Concrete Surface	1.80

(Reference 79)

TABLE 10. TYPICAL AASHTO STRUCTURAL LAYER COEFFICIENTS

Type of Recycled Material	Layer	Range of a_1 Computed	Average a_1	Number of Test Sections	a_1 for Corresponding Layer and Material at AASHTO Road Test
Central Plant Recycled Asphalt Concrete Surface	Surface	0.37-0.59	0.48	14	0.44
Central Plant Recycled Asphalt Concrete Base	Base	0.37-0.49	0.42	3	0.35
In-Place Recycled Asphalt Concrete Stabilized with Asphalt and/or an Asphalt Modifier	Base	0.22-0.49	0.39	6	0.35
In-Place Recycled Asphalt Concrete and Existing Base Material Stabilized with Cement	Base	0.23-0.42	0.33	4	0.15-0.23
In-Place Recycled Asphalt Concrete and Existing Base Stabilized with Lime	Base	0.40	0.40	1	0.15-0.30
In-Place Recycled Asphalt Road Mix Stabilized with Asphalt	Surface	0.42	0.42	1	

(Reference 80)

SECTION IX
PROJECT SELECTION AND ECONOMICS

PROJECT SELECTION

Figure 20 (Reference 6) shows the overall concept of pavement rehabilitation. It is obvious that recycling is only one of several alternatives. Selection of one of the available options should be based upon observed pavement distress, establishment of the probable causes of distress on the basis of field and laboratory study, and design input such as

1. History of maintenance requirements and costs
2. History of pavement performance
3. Horizontal and vertical geometric controls
4. Environmental factors
5. Traffic

Once recycling has been selected as the means of rehabilitation to be used, the NCHRP guidelines (Reference 57) can be used for selecting the most appropriate recycling method. The following is a summary of the guidelines.

The first step is to characterize the existing facility using historical records and known conditions. In addition, the present condition of the facility must be measured and compared to a standard. Factors that will influence the decision include surface conditions, structural conditions, roughness, and skid resistance.

Existing Facility

The first factor to be considered with respect to the existing facility is the location and size of the project. Projects located in remote areas will have to be large enough to justify the transportation of equipment associated with central plant recycling. Small, low-traffic-volume projects located in remote areas would be more suited for in-place recycling.

Pavement class is another consideration. Air Force pavements are classified as Types A, B, or C depending upon volume of traffic and weight of

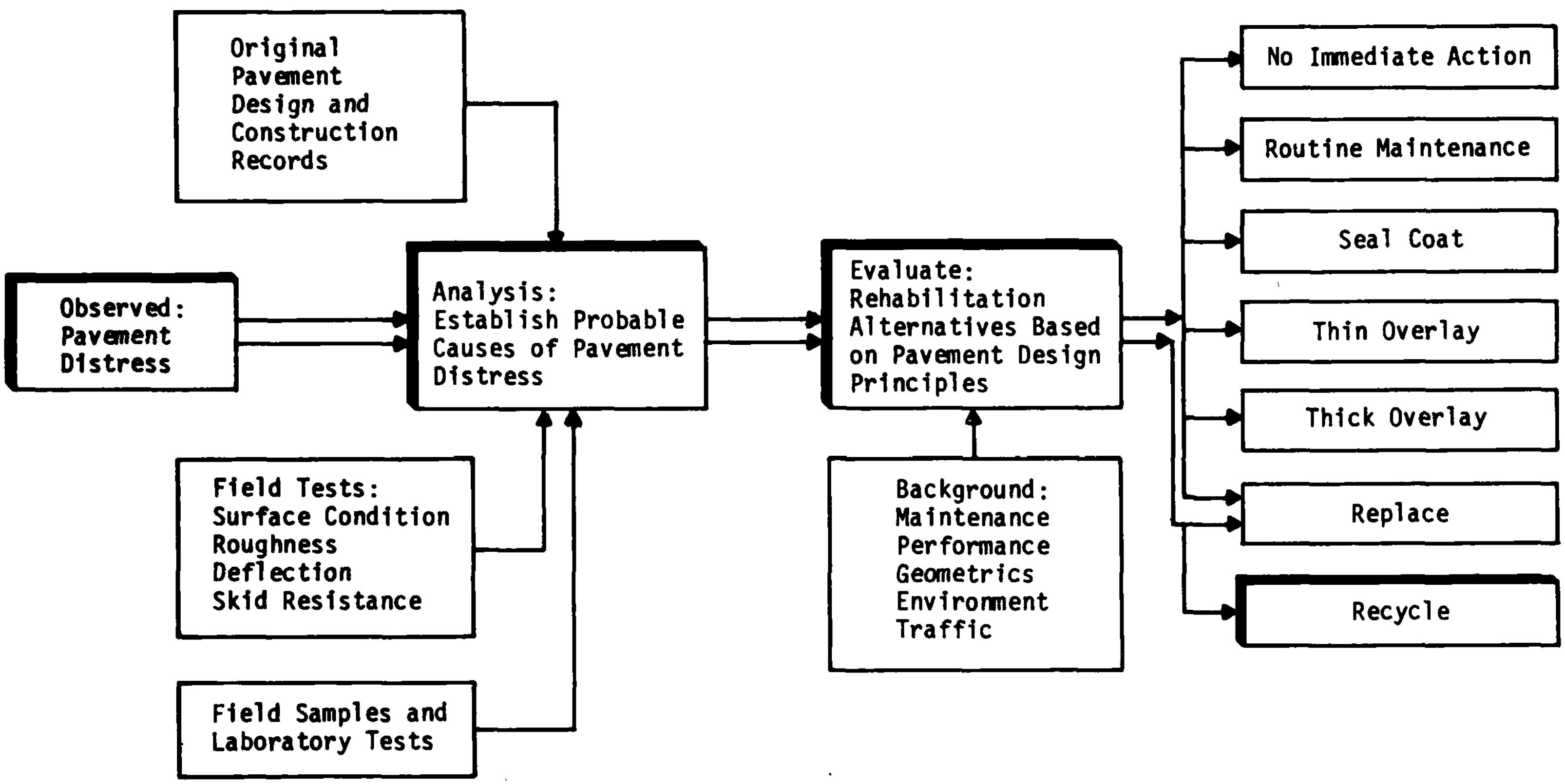

Figure 20. Recycling as a Rehabilitation Alternative (after Reference 6)

aircraft handled. The operational and design categories of the pavement are also important in the determination of the need for pavement rehabilitation as well as serving as criteria for the selection of a recycling process.

The construction history of the facility is used to judge the serviceability of the pavement. The presence of overlays, seal coats, or crack filling will influence the decision about which recycling method is to be used. Project records can provide information about the thickness of the various pavement materials as well as the types of materials and their condition. A few carefully placed core samples will give confidence in such information.

The geometric features of a facility, such as horizontal and vertical alignment, are often constraints to conventional rehabilitation techniques. Multiple overlays, which can create excessively high crowns at the centerline and steep cross slopes, may be a problem. Such features as drainage inlets and manholes cause problems of the same nature. Recycling offers a solution to many of these problems. Changing the horizontal alignment or adding new features, such as new or wider shoulders, may also present opportunities to use recycling. The new features may not need to have the full design strength of the adjoining feature and could be stabilized in place. The existing aggregate base could be conserved and used in asphaltic concrete without the addition of new materials.

The volume and gear weight distribution of traffic are important from a pavement design standpoint. For pavement design purposes, it is suggested that traffic figures be converted to average daily coverages that are representative for the design period. It is suggested that Air Force procedures be used for this conversion.

Pavement failures due to subgrade conditions should also be considered. A subgrade containing swelling clay must be improved before the pavement materials can be effectively recycled. Frost heave is another environmentally influenced problem related to volume change. Because the pavement materials would have to be removed before the subgrade problem could be corrected, they could be reprocessed and replaced after the subgrade improvement had been effected.

Surface Condition--Each potential recycling project should be surveyed for surface defects. The survey can then be used to assess the causes of distress and perhaps to suggest a course of corrective action. It is suggested that the Air Force use the Pavement Condition Index system. Once the survey has been completed, the results can be summarized on the first line of the form shown in Table 11 (Reference 6). All of the typical pavement distress types are displayed across the top of the table, and all of the recycling alternatives are listed at the left. The engineer should look at each type of distress marked on the first line, determine which recycling method would be appropriate, and place a check mark in the corresponding box. The shaded boxes indicate recycling alternatives that would not be appropriate to a given situation. Once the recycling alternatives that would improve the surface condition have been identified, they can be summarized on the form shown in Table 12 (Reference 6).

Structural Condition--The required thickness of the overlay will determine the structural condition or adequacy of the pavement. These requirements are determined by deflection-based procedures. Table 13 shows that some recycling alternatives can be eliminated on the basis of the required thickness of the overlay. Those recycling alternatives considered appropriate for improving the structural adequacy of the pavement should be entered in Table 12.

Roughness--In many cases, the roughness of the pavement will be a deciding factor. It is possible that the rough surface will be the only significant problem and that surface recycling would be the solution. If other deficiencies that require more extensive treatment are present, the surface roughness should be corrected automatically by that treatment. Therefore, the need for surface recycling can be estimated on the basis of profilometer measurements. When roughness has been determined to be a problem, it can be noted in Table 12.

Skid Resistance--Excess asphalt cement or polished aggregate may cause a pavement to lose skid resistance. Skid resistance is an important Air Force criterion. All of the recycling methods except heater planing or heater scarifying alone will improve skid resistance. The appropriate recycling methods should be noted in Table 12.

TABLE 11. SELECTION OF RECYCLING TECHNIQUES ON BASIS OF ROADWAY CONDITIONS

	Recycling Methods	Condition of Existing Pavement
Surface	Heater Planer Without Additional Aggregate	A1
	Heater Planer With Additional Aggregate	A2
	Heater Scarify	A3
	Heater Scarify Plus Thin Overlay	A4
	Heater Scarify Plus Thick Overlay	A5
	Surface Milling	A6
	Surface Milling Plus Thin Overlay	A7
	Surface Milling Plus Thick Overlay	A8
In-Place	Thin Asphalt Concrete-Minor Structural Improvement Without New Binder	B1
	Thin Asphalt Concrete-Minor Structural Improvement With New Binder	B2
	Thin Asphalt Concrete-Major Structural Improvement Without New Binder	B3
	Thin Asphalt Concrete-Major Structural Improvement With New Binder	B4
	Thick Asphalt Concrete-Minor Structural Improvement Without New Binder	B5
	Thick Asphalt Concrete-Minor Structural Improvement With New Binder	B6
	Thick Asphalt Concrete-Major Structural Improvement Without New Binder	B7
	Thick Asphalt Concrete-Major Structural Improvement With New Binder	B8
Central Plant	Cold Process-Minor Structural Improvement Without New Binder	C1
	Cold Process-Minor Structural Improvement With New Binder	C2
	Cold Process-Major Structural Improvement Without New Binder	C3
	Cold Process-Major Structural Improvement With New Binder	C4
	Hot Process-Minor Structural Improvement Without New Binder	C5
	Hot Process-Minor Structural Improvement With New Binder	C6
	Hot Process-Major Structural Improvement Without New Binder	C7
	Hot Process-Major Structural Improvement With New Binder	C8

Type of Distress: Rutting (% of Area); Raveling (% of Area: 1-15, 16-30, 30); Flushing (% of Area: 1-15, 16-30, 30); Corrugations (% of Area: 1-15, 16-30); Alligator Cracking (% of Area: 1-5, 6-15, 16); Longitudinal Cracking (Lin Ft per Station); Transverse Cracking (No per Sta: 1-4, 5-9); Patching (% of Area: 1-5, 6-15, 16). Each range subdivided into Slight, Moderate, Severe, with a None column for each distress type.

(Reference 6)

TABLE 12. SUMMARY OF PRELIMINARY RECYCLING ALTERNATIVES

Recycling Methods				Surface Condition	Deflection	Roughness	Skid-Resistance
Surface	Heater Planer	Without Additional Aggregate	A1				
		With Additional Aggregate	A2				
	Heater Scarify	Heater Scarify Only	A3				
		Heater Scarify Plus Thin Overlay or Aggregate	A4				
		Heater Scarify Plus Thick Overlay	A5				
	Surface Milling or Grinding	Surface Milling Only	A6				
		Surface Milling Plus Thin Overlay	A7				
		Surface Milling Plus Thick Overlay	A8				
In-Place	Asphalt-Concrete Surface Less Than 125 mm (5 in)	Minor Structural Improvement Without New Binder	B1				
		Minor Structural Improvement With New Binder	B2				
		Major Structural Improvement Without New Binder	B3				
		Major Structural Improvement With New Binder	B4				
	Asphalt-Concrete Surface Greater Than 125 mm (5 in)	Minor Structural Improvement Without New Binder	B5				
		Minor Structural Improvement With New Binder	B6				
		Major Structural Improvement Without New Binder	B7				
		Major Structural Improvement With New Binder	B8				
Central Plant	Cold-Mix Process	Minor Structural Improvement Without New Binder	C1				
		Minor Structural Improvement With New Binder	C2				
		Major Structural Improvement Without New Binder	C3				
		Major Structural Improvement With New Binder	C4				
	Hot-Mix Process	Minor Structural Improvement Without New Binder	C5				
		Minor Structural Improvement With New Binder	C6				
		Major Structural Improvement Without New Binder	C7				
		Major Structural Improvement With New Binder	C8				

(Reference 6)

TABLE 13. SELECTION OF RECYCLING TECHNIQUES TO IMPROVE STRUCTURAL STRENGTH ON BASIS OF PAVEMENT DEFLECTION

Recycling Methods			Thickness of Required Overlay		
			None	Less Than 2 in	Greater Than 2 in
Heater Planer	A1	Without Additional Aggregate			
	A2	With Additional Aggregate			
Heater Scarify	A3	Heater Scarify Only			
	A4	Heater Scarify Plus Thin Overlay or Aggregate			
	A5	Heater Scarify Plus Thick Overlay			
Surface Milling or Grinding	A6	Surface Milling Only			
	A7	Surface Milling Plus Thin Overlay			
	A8	Surface Milling Plus Thick Overlay			
Asphalt-Concrete Surface Less Than 125 mm (5 in)	B1	Minor Structural Improvement Without New Binder			
	B2	Minor Structural Improvement With New Binder			
	B3	Major Structural Improvement Without New Binder			
	B4	Major Structural Improvement With New Binder			
Asphalt-Concrete Surface Greater Than 125 mm (5 in)	B5	Minor Structural Improvement Without New Binder			
	B6	Minor Structural Improvement With New Binder			
	B7	Major Structural Improvement Without New Binder			
	B8	Major Structural Improvement With New Binder			
Cold-Mix Process	C1	Minor Structural Improvement Without New Binder			
	C2	Minor Structural Improvement With New Binder			
	C3	Major Structural Improvement Without New Binder			
	C4	Major Structural Improvement With New Binder			
Hot-Mix Process	C5	Minor Structural Improvement Without New Binder			
	C6	Minor Structural Improvement With New Binder			
	C7	Major Structural Improvement Without New Binder			
	C8	Major Structural Improvement With New Binder			

(Reference 6)

Determining Recycling Alternatives

As has been mentioned, this preliminary study is made to determine several reasonable alternatives. Once this has been done, the options can be analyzed in terms of cost and energy savings. The following steps are used to reach these conclusions:

1. List available information on the existing facility.
2. Test the pavement surface condition, structural condition, roughness, and skid resistance.
3. Evaluate other factors unique to the project.
4. Make a preliminary cost analysis based upon representative costs found in Reference 6.
5. Consider the most attractive alternatives and continue the evaluation (see Reference 6).

ECONOMICS AND ENERGY

Cost and energy comparisons will play a major role in the selection of the most appropriate recycling alternative for a given project. Finn (Reference 81) has outlined a method for selecting the appropriate recycling operations, and Halstead (Reference 82) has defined cost and energy considerations associated with project selection.

Cost Considerations

The initial and recurring costs that an agency may consider in an economic evaluation of rehabilitation strategies are outlined in Reference 83. These considerations, which have been modified slightly to reflect Air Force concerns, include the following:

1. Costs
    a. Initial capital costs of rehabilitation
    b. Future capital costs of reconstruction or rehabilitation
    c. Maintenance costs throughout the design period
    d. Salvage value at the end of the design period

e. Engineering and administration

f. Costs of investment

2. Operations concerns

a. Aircraft operational delay

b. Accidents

c. Discomfort

d. Time delay and extra vehicle operating costs during resurfacing or major maintenance operations

The reader is again referred to Reference 6 for estimates of the initial capital costs of various recycling, construction, and rehabilitation operations.

SECTION X
MILITARY APPLICATIONS

FIELD EXPERIENCE

Although asphalt pavement recycling is a fairly recent development, it is by no means strange to the military. In 1962 Koppers Company, Inc., performed surface recycling jobs at Dover Air Force Base, Delaware, and at Daniel Field, Georgia. These projects involved heater scarification of the surface followed by the application of a rejuvenating agent. The construction reports noted that the process had successfully eliminated surface defects in the pavement (References 84 and 85). Brown (Reference 15) reports that heater-planer-scarifier operations were performed at Craig Air Force Base, Alabama; Galena and Shemya Air Force Bases, Alaska; and Thule Air Force Base, Greenland, before overlays were placed on these pavements. Cold milling was performed on the runway at Myrtle Beach Air Force Base, South Carolina, to remove rubber build-up and the cracked and oxidized asphalt surface before a 2-inch asphalt concrete overlay was placed. The Air Force has also used cold milling in Alaska, Maine, New Hampshire, Colorado, Oklahoma, and California. Surface rejuvenators, used alone or in conjunction with heater-planer-scarifier or milling operations, have been employed at Lajes Field, the Azores; at Wright-Patterson Air Force Base, Ohio; and at other bases throughout the United States. This process is not suggested for runways because the skid resistance of the pavement tends to decrease after the surface rejuvenator is applied. It is, however, recommended for use on taxiways and parking aprons, where skid resistance is not so critical (Reference 15).

A large-scale project in central plant recycling took place at Pope Air Force Base, North Carolina. This job was done during the summer of 1980. It encompassed the repair of distressed portions of the runway, three taxiways, and a hot spot area.* This project consisted of

1. Removal of 5929 m^2/mm (180,135 yd^2/in) of existing asphalt concrete by cold milling.
2. Removal and disposal of 3,319 m^3 (4,345 yd^3) of the existing base.

*Statement of Physical Magnitude, Project P041-8: Repair Airfield Pavements, Pope Air Force Base, North Carolina, 1980.

3. Removal of 3,500 m^2 (4,200 yd^2) of PCC.

4. Placement of 484 m^3 (633 yd^3) of select fill.

5. Placement of 14,946 tonnes (16,479 tons) of recycled asphalt concrete.

6. Slurry sealing 7.954 m^2 (9,515 yd^2).

7. Paint stripping 732 m (2,400 ft).

8. Use of 19,500 litres (4,430 gal) of curing compound.

9. Placement of 3,587 tonnes (3,955 tons) of asphalt concrete wearing course.

Figure 21* is a layout of the Pope Air Force Base airfield showing the recycled areas. Figure 22* shows the proposed cross sections for these areas. Not shown is a cross section in which the recycled asphalt pavement was used as the wearing course. This material was placed on a small portion of taxiway six.**

The central plant used in this project was a batch plant located approximately 5.6 kilometers (3.5 miles) from the job site. A 50-50 blend of recycled and virgin material was used. Mr. Don Brown of the Air Force Civil Engineering Center and Mr. Ray Brown of the Corps of Engineers Waterways Experiment Station (WES) were present during construction. They noted that the compaction of the recycled mixture was 97.2 percent of the optimum as opposed to the 98 percent specified. Another problem they noted was a lack of control over the surface temperature of the mixture. Also, the contractor had no positive grade control on his asphalt lay-down machine. This airfield is now under observation by WES.

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*Construction Records for Project P041-8, 1980.

**Interview with Mr. Don Jessup, Pavement Engineer, Pope Air Force Base, North Carolina, in October 1980.

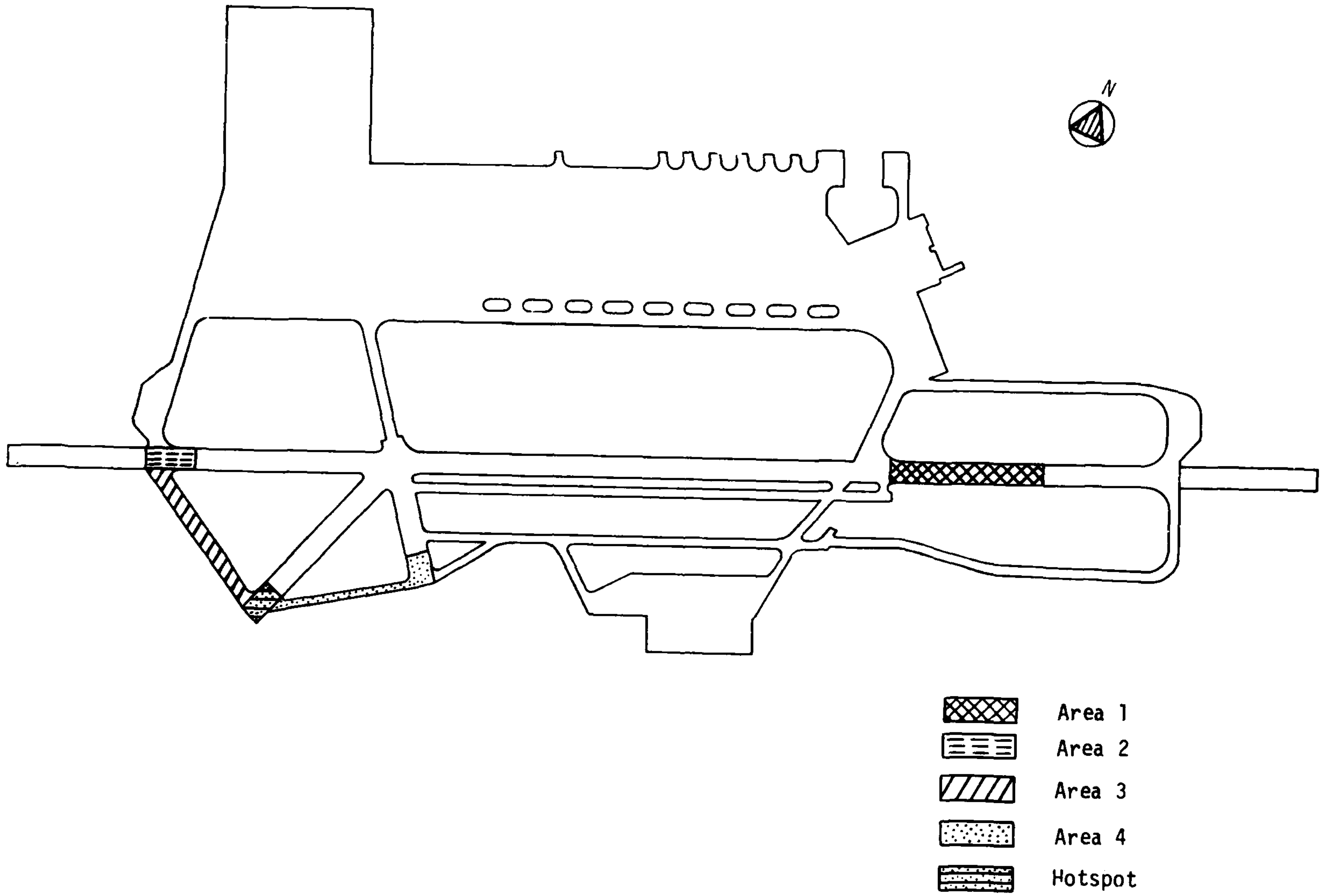

Figure 21. Layout of Recycled Areas at Pope Air Force Base

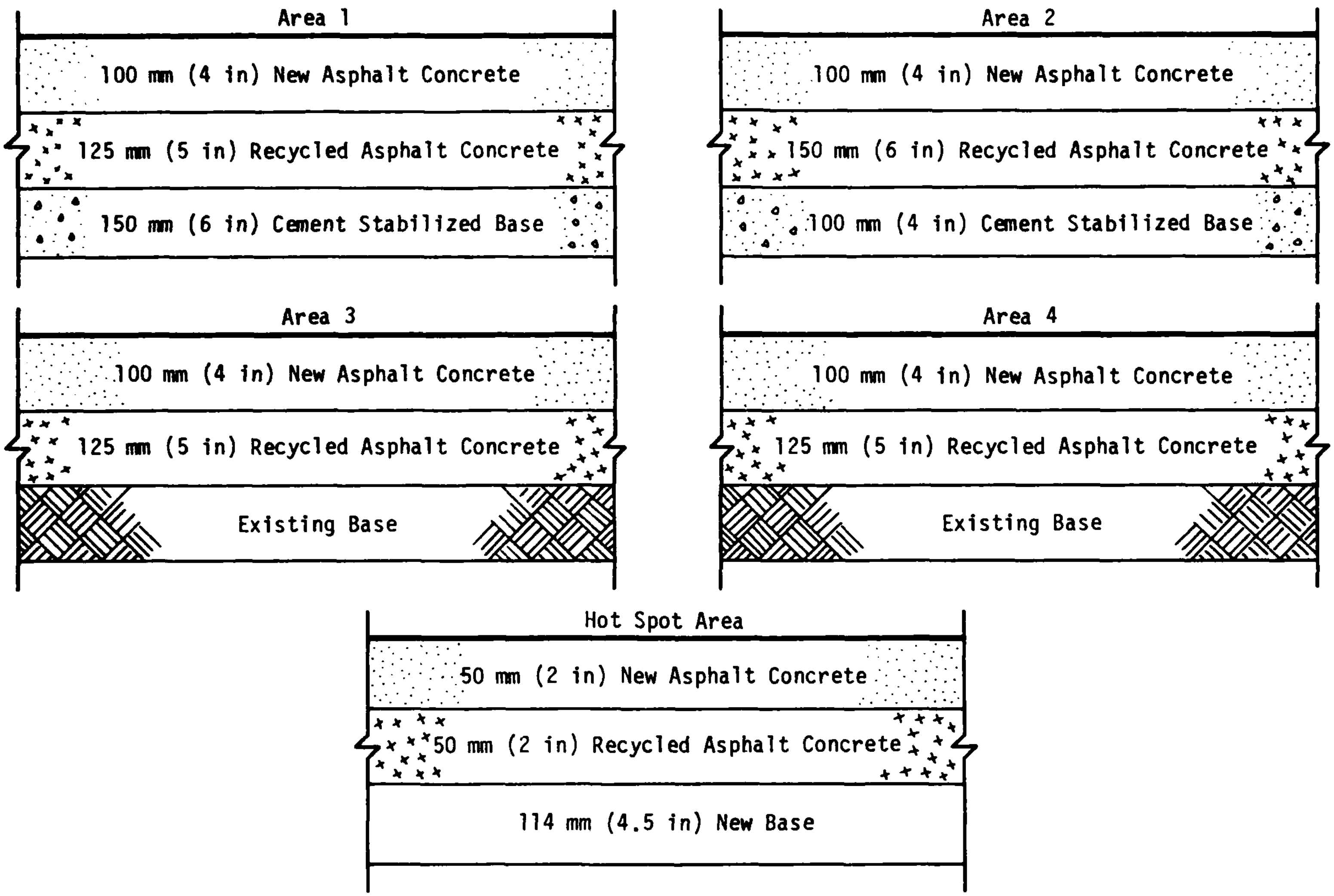

Figure 22. Cross Sections Proposed for Recycled Asphalt Pavements at Pope Air Force Base

Additional recycling projects on airfield pavements are planned for the near future.* A hot-mix recycling job will be done at Lajes Field, the Azores, during the spring of 1981. This project will encompass the entire airfield. Hot recycling techniques will be used for both the base and the surface courses. A cold recycling project has been scheduled for McGuire Air Force Base, New Jersey, during the current fiscal year. WES will monitor both of these projects.

White reports (Reference 86) that a hot-mix recycling project was conducted at WES during 1976, in preparation for an asphalt recycling project to be conducted at Columbus Air Force Base, Mississippi. The preliminary study at WES demonstrated that asphalt mixtures could be successfully manufactured from recycled pavements.

The Air Force Institute of Technology at Wright-Patterson Air Force Base, Ohio, has also conducted research in asphalt pavement recycling. One project dealt with asphalt rejuvenators and their applications (Reference 87). A result of this project was the development of a guide for the use of rejuvenators in surface recycling. In another project, Carmichael et al. reported modeling heater techniques used in surface recycling (Reference 88). This study was conducted for a better understanding of the effects of heat application on asphalt pavements.

LABORATORY EXPERIENCE

An extensive laboratory study was undertaken by Brownie and Hironaka at the Naval Construction Battalion Center in Port Hueneme, California (Reference 16). Their report presents criteria and guidelines for the recycling of existing asphalt-concrete airfield pavements for the Navy and the Federal Aviation Administration (FAA). It emphasizes cold-mix and hot-mix recycling.

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*Conversations with Mr. Charles York, Command Pavement Engineer, Military Airlift Command, and Mr. L. Nelson Godwin, Civil Engineer, U.S. Army Engineer Waterways Experiment Station, Tyndall Air Force Base, Florida, in November 1980.

The report proposes test procedures and standards for evaluating potentially recyclible asphalt concrete, softening agents, and recycled mixtures. These are listed in Tables 14, 15, and 16. Guidelines for use by the Navy and the FAA are shown in Figures 23 and 24 (Reference 16).

Brownie and Hironaka concluded that a reasonable linear relationship exists between recycling agent concentration and the log of viscosity or penetration for recycling agent-residual asphalt blends of up to 50-50. They also found that softening agents in combination with residual asphalts produce materials that seem to have most of the physical properties of new asphalt cements. The study stresses that each recycling agent must be tested with the particular asphalt to be recycled (Reference 16).

With regard to hot-mix recycling, Brownie and Hironaka suggest the use of conventional mix design procedures. These researchers warn that crushing operations change the gradation of the recycled mixture and that adjustments are necessary. However, aggregate adjustments are necessary in any case because the reclaiming agent raises the asphalt content over the optimum. Brownie and Hironaka discovered difficulties in introducing antistripping admixtures to recycled mixtures. Therefore, existing pavements that show a tendency for stripping may not be suitable for hot-mix recycling (Reference 16).

In their study of cold-mix recycling, Brownie and Hironaka used unstabilized, portland-cement-treated, and asphalt-emulsion-treated base courses. They found that unstabilized recycled pavements produced an acceptable base only when crushed rock was added to the base material. However, they also noted that in-place methods of crushing seemed to produce an angular material that compacted better than laboratory-prepared material. It was their observation that a design California Bearing Ratio (CBR) of 80 is adequate for recycled base courses providing that all other criteria are met. The compressive strengths of portland-cement-treated bases did not meet current FAA and Navy specifications. The asphalt-emulsion-treated recycled base materials were found acceptable only for pavements serving aircraft weighing less than 13,600 kg (30,000 lbs) (Reference 16).

TABLE 14. TEST PROCEDURES AND STANDARDS FOR EVALUATING POTENTIAL RECYCLIBLE ASPHALT CONCRETE

Type of Test	Test Standard	Used For				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix With			
			No Additive	Asphalt	Portland Cement	
Quantity of Asphalt in Mixture	ASTM D2172	Yes	No	Yes	No	For mix design
Recovery of Asphalt Cement	ASTM D1856	Yes	No	Yes	No	For mix design and further testing
Penetration of Recovered Asphalt Cement	ASTM D5	Yes	No	Yes	No	For determining softener requirements[a]
Absolute Viscosity of Recovered Asphalt Cement	ASTM D2171	Yes	No	Yes	No	For determining softener requirements[a]
Abrasion Resistance of Coarse Aggregate	ASTM C128	Yes	Yes	Yes	Yes	For intended use as given in current FAA or Navy specifications
Moisture-Density Relationship	ASTM D1557	No	Yes	No	Yes	Construction control
Aggregate Gradation	ASTM C136	Yes	Yes	Yes	Yes	For intended use as given in current FAA or Navy specifications
Liquid Limit	ASTM D423	No	Yes	Yes	Yes	For intended use as given in current FAA or Navy specifications
Plastic Limit	ASTM D424	No	Yes	Yes	Yes	For intended use as given in current FAA or Navy specifications
Sand Equivalent	ASTM D2419	No	Yes	Yes	Yes	For intended use as given in current FAA or Navy specifications

(Reference 16)

a. A lower limit of penetration and an upper limit of viscosity for recyclible asphalt have not been precisely defined. Testing of residual asphalt and softener blends is relied on to determine adequacy of binder material.

TABLE 15. PRELIMINARY SOFTENING AGENT CRITERIA

Type of Test	Test Standard	Limiting Values	Use of Results
Softener Only[a]			
Kinematic Viscosity	ASTM D2170	80-500 centistokes at 140°F	Measure of ease of dispersion in mix
Flash Point	ASTM D92	390°F (minimum)	Handling safety
Composition Analysis[b]	ASTM D2006	$N/P > 1.0$, $N+A_1/P+A_2 = 0.4$ to 1.0	Compatibility and durability
Softener/Residual Asphalt Blend			
Absolute Viscosity, poises at 140°F	ASTM D2171	As specified	Blend viscosity or penetration; match asphalt grade used for new construction
Penetration, 77°F	ASTM D5	As specified	Use method in use in local area
Thin Film Oven Test	ASTM D1754	---	Aging of blend to assess durability
Residue After Thin Film Oven Test			
Retained Penetration, Percent of Blend Original, 77°F	ASTM D5	Minimum 40	Measure of durability
Increase in Viscosity, Percent of Blend Original, Poises at 140°F	ASTM D2171	Maximum 500 percent	Measure of durability
Ductility, 77°F, 5 cm/min	ASTM D113		Measure of durability and adhesion
Blends with original penetration > 140 or viscosity < 750 P		Minimum 100 cm	
Blends with original penetration < 140 or viscosity > 750 P		Minimum 75 cm	

(Reference 16)

a. Applies only to active oil portion if softener is emulsified.

b. For paving grade asphalts, this test not required if candidate material has a good record of performance.

TABLE 16. TEST PROCEDURES AND STANDARDS FOR EVALUATING RECYCLED MIXES

Type of Test	Test Standard	Used For				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix With			
			No Additive	Asphalt	Portland Cement	
Marshall Stability	ASTM D1559 or MIL-STD 620A, Method 100	Yes	No	Yes	No	Determination of stability 1800-lb minimum; other properties from specifications for intended use
Theoretical Maximum Specific Gravity	ASTM D2041	Yes	No	Yes	No	Determination of air voids and voids filled
Bulk Specific Gravity	ASTM D1188	Yes	No	Yes	No	Determination of optimum asphalt content and for voids analysis
Immersion Compression Test	MIL-STD 620A, Method 104	Yes	No	Yes	No	Stripping potential; index of retained stability must be >75
Penetration	ASTM D5	Yes	No	Yes	No	Consistency of asphalt/softener blend; matching of penetration of added virgin asphalt or grade normally used
Absolute Viscosity	ASTM D2171	Yes	No	Yes	No	Consistency of blend; matching of viscosity of asphalt grade normally used
California Bearing Ratio	ASTM D1883 or MIL-STD 621A, Method 100	No	Yes	No	No	Evaluation of subbase and base course blends; minimum CBR = 80; subbase course minimum CBR = 40
Compressive Strength	ASTM D1633	No	No	No	Yes	Cement-treated base; minimum 750 lb/in^2 at 7 days
Wet-Dry Tests	ASTM D558	No	No	No	Yes	Weight loss after 12 cycles <14 percent
Freeze-Thaw Tests	ASTM D559	No	No	No	Yes	Weight loss after 12 cycles <14 percent
Sieve Analysis	ASTM C136	Yes	Yes	Yes	Yes	Conformance to specifications for intended use
Liquid Limit	ASTM D423	No	Yes	No	Yes	Conformance to specifications for intended use
Plastic Limit	ASTM D424	No	Yes	No	Yes	Conformance to specifications for intended use
Sand Equivalent	ASTM D2419	No	Yes	No	Yes	Conformance to specifications for intended use

(Reference 16)

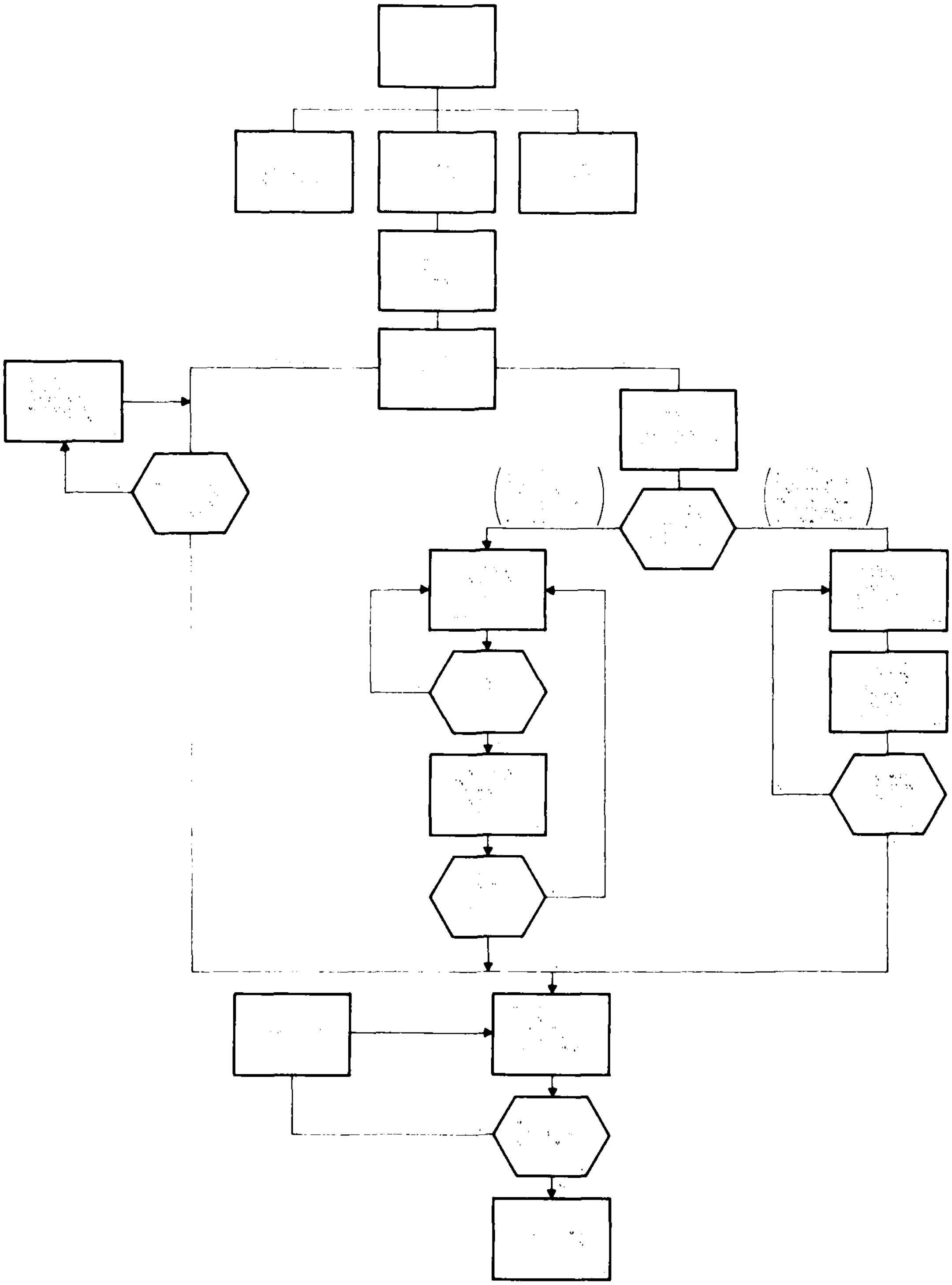

Figure 23. Flow Chart: Hot-Mix Design Guidelines (after Reference 16)

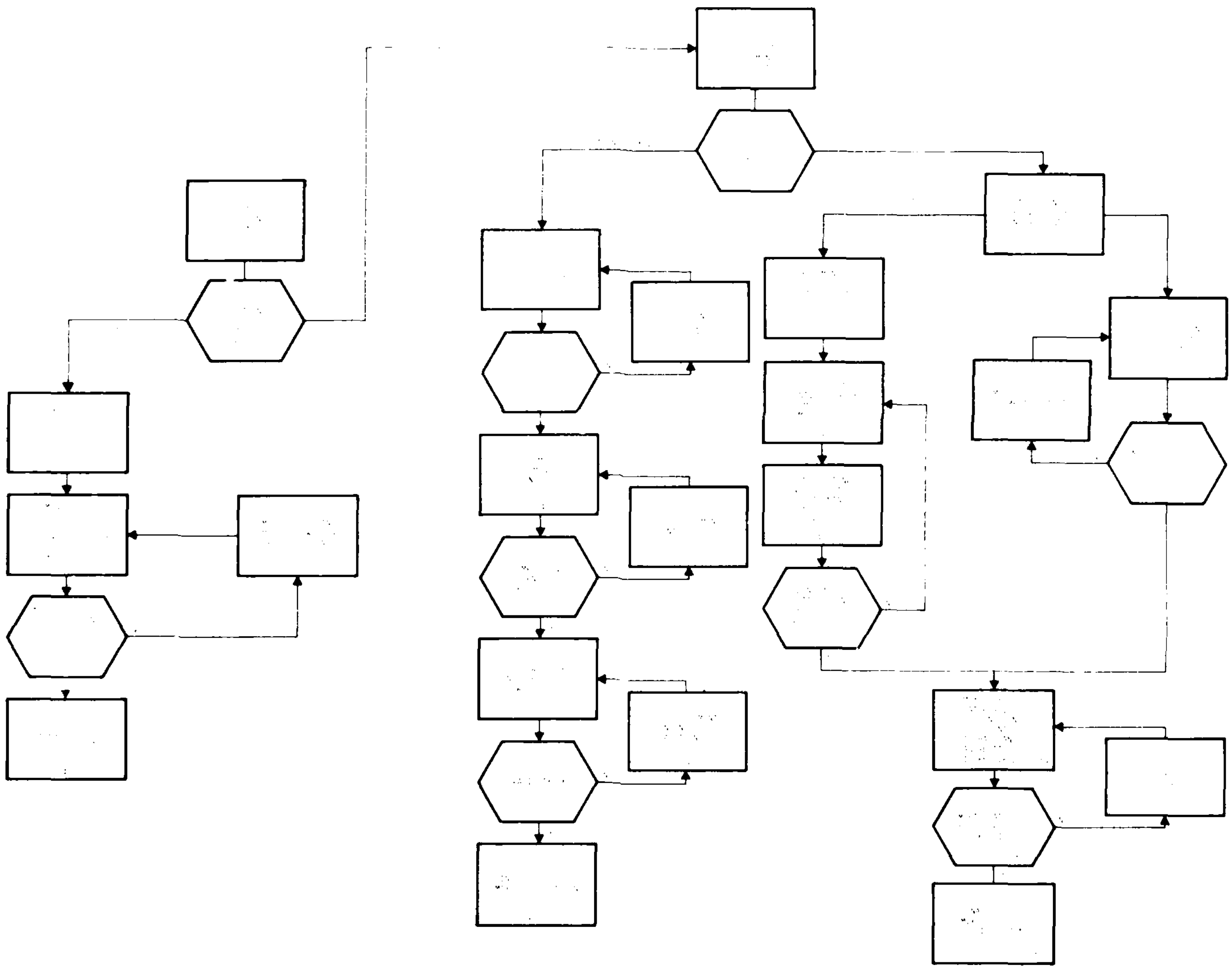

Figure 24. Flow Chart: Cold-Mix Design Guidelines (after Reference 16)

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ASPHALT RECYCLING TECHNOLOGY: LITERATURE REVIEW AND RESEARCH PL--ETC(U)
JUN 81   D E NEWCOMB, J A EPPS   F29601-76-C-0015
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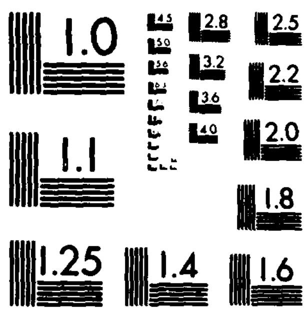
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

After a study conducted at WES, Lawing suggested that the Air Force initiate laboratory programs to determine which tests and limits should be used to measure the quality of materials considered as candidates for recycling. He also recommended that tests and limits be developed for recycled materials (Reference 14). As a result of another study at WES, Brown stated that guide specifications should be written for each type of recycling process and that a standard practice manual explaining how and when to use each recycling process should be developed. He suggested that a better understanding of the durability, strength, and fatigue properties of recycled asphalt pavements is needed. Brown also proposed the development of criteria for the use of recycling agents (Reference 15).

SECTION XI
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

On the basis of the studies described in this report, it can be generally concluded that asphalt pavement recycling has proven to be a useful rehabilitation and maintenance option. Dr. Rudy Jimenez, in a presentation to the National Seminar on Asphalt Recycling, stated: "Recycling is no longer an art; it is a science."* Others have agreed with his assessment.

More specifically, it can be concluded that

1. Guidelines exist to aid the engineer and contractor in the design and construction of recycled pavements.

2. Surface, cold, and hot recycling techniques have been included in a number of demonstration projects. In the majority of these projects, recycling has been shown to be economical and energy-conserving.

3. A number of laboratory studies have been conducted on recycling agents, and the results of these studies are available to aid in the choice of modifiers for any particular project.

4. The military has had experience in laboratory testing and field applications of recycled pavements. This experience should provide the basis for future research and more extensive recycling projects.

RECOMMENDATIONS

While pavement recycling is recognized as a useful alternative for the present, a better understanding is needed in a number of areas. With this in mind, the following research recommendations are submitted:

1. Criteria should be developed for the preliminary selection of recycling alternatives for airfield pavements.

2. Recycling projects should be subjected to performance evaluations. Such evaluations should relate to the pavement distress that the recycling operation was intended to correct.

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*Dallas-Fort Worth Airport, Texas, 1980.

3. Better specifications and quality control techniques should be developed for pavement recycling operations.

4. Improved specifications for pavement modifiers are needed.

5. The interaction between modifiers and old recycled asphalt cements must be better defined.

6. Laboratory tests should be conducted to investigate the use of soft asphalts in place of recycling agents.

7. An extensive laboratory evaluation of recycled asphalt concrete should be undertaken to establish fatigue characteristics and permanent deformation and creep properties. The performance of this material may then be predicted by mechanistic systems such as PREDICT.

8. The in situ properties of both conventional and recycled materials should be defined.

9. The water susceptibility and durability of recycled materials should be better defined.

10. Laboratory mixture design methods must be established for cold in-place recycling operations.

11. The use of recycled materials in pavement surface course applications should be investigated.

12. Cost and energy requirements for recycling operations ought to be better defined.

13. Manuals that describe when to use recycling, how to recycle, and the cost of recycling versus other pavement rehabilitation alternatives should be developed.

14. The Air Force should initiate research programs to investigate PCC recycling.

15. Air-transportable recycling equipment and associated recycling techniques should be developed for use in national emergencies.

SECTION XII
RECOMMENDED RESEARCH APPROACH

INTRODUCTION

The recommended research program is described here under the following six headings:

1. Implementation
2. Mixture Design for Asphalt Pavement Recycling
3. Portland Cement Concrete Recycling
4. Expedient Pavement Recycling in Military Operations
5. Performance Monitoring
6. Other Considerations

These groups are further subdivided into specific research topics. Each topic is given a priority of A, B, or C depending upon its relative importance to the Air Force's mission. Priority A encompasses those needs which are most urgent, and priority C encompasses those needs which have comparatively little payoff for the Air Force. Priority B topics should be researched but are not necessarily required for the implementation of the project as a whole.

A general scope and cost estimate is given for each proposed research task. The scope of the task may change depending upon the contractor chosen to perform the work. The actual cost for each task may differ from the estimate depending upon the contractor selected and the rate of inflation. The cost estimates presented here are based on 1981 costs, and standard Air Force policy has been adopted to account for inflation.

This section concludes with a summary containing a master schedule of the research. The schedule includes priorities, effort levels, time allocations, and budget estimates.

DATA BASE

Inasmuch as the various tasks included in this effort will be performed by several agencies and institutions, it is recommended that one of these

organizations be used as a data base. Ideally, this would be the organization responsible for the preparation of asphalt recycling manuals.

This contractor would be responsible for receiving and reviewing progress reports. Progress and data would be scrutinized for consistency. Any delays or unusual data would be promptly investigated. Corrective action would be initiated if required.

It is also recommended that this contractor form and coordinate a panel of experts who will review the research effort. This panel could include representatives from each organization performing research for the Air Force. The panel members would receive and review progress reports throughout the course of the asphalt recycling effort.

At the end of the research effort, this contractor would develop manuals for the Air Force based upon the research data that has been collected.

Table 17 shows that in order for this organization to function for the entire time span of the research effort, approximately $320,000 would be required.

TABLE 17. OPERATING REQUIREMENTS FOR DATA BASE

Priority: A
Time Allotted: 48 months
Personnel Requirements:
a. Professional: 2.2 man-years
b. Support: 1.8 man-years
Budget: $320,000
Fiscal Year: 1982-1985

IMPLEMENTATION

A vast amount of information on pavement recycling is currently available. It is therefore suggested that the Air Force draw upon this state-of-the-art to develop its own recycling program. The program should be flexible enough to allow periodic upgrading as new information becomes available.

Training Packages

Training aids based on existing Air Force manuals and policies could be developed to educate personnel on asphalt pavement recycling. Training materials could be produced in the form of slide presentations or films. This series should include one presentation giving an overview of asphalt concrete recycling and one presentation on each of the three recycling categories (hot, cold, and surface).

The organization chosen to develop these training packages should have personnel who are intimately familiar with asphalt pavement recycling techniques. Table 18 shows that these productions should require about 12 months and $104,000. This work is considered to be high priority because it is related to implementation.

TABLE 18. PRODUCTION OF TRAINING PACKAGES

Priority: A
Time Allotted: 12 months
Personnel Requirements:
a. Professional: 1.0 man-year
b. Support: 0.3 man-year
Budget: $104,000
Fiscal Year: 1982

Pavement Thickness Design

Pavement thickness for recycled asphalt concrete pavements is usually designed in accordance with standard practice. As more information becomes available, it may be shown that with certain recycling techniques a thinner pavement section can be used. Therefore, it is suggested that the state-of-the-art be reviewed in fiscal year 1985 to determine whether any advances in pavement thickness design have been made. This priority A project should require about 8 months and $68,000 to complete (Table 19).

TABLE 19. PAVEMENT THICKNESS DESIGN DEVELOPMENT

Priority: A
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.6 man-year
b. Support: 0.2 man-year
Budget: $68,000
Fiscal Year: 1985

Update of Existing Recycling Manuals

At the end of the total research program, all the information obtained should be reviewed and the recycling manual should be updated. In addition to changes in design procedures and specifications, a section on expedient recycling operations could be included. This update should be performed by the data base organization. This high-priority project should require about 12 months and $134,000 to complete (Table 20).

TABLE 20. UPDATE OF RECYCLING MANUAL

Priority: A
Time Allotted: 12 months
Personnel Requirements:
a. Professional: 1.0 man-year
b. Support: 0.3 man-year
Budget: $134,000
Fiscal Year: 1986

MIXTURE DESIGN FOR ASPHALT PAVEMENT RECYCLING

This group of research projects is oriented toward developing mixture design techniques for various recycling operations. The information gained

through these efforts will be used to upgrade the pavement recycling manual, which will already be in use. The subjects that merit study under this heading include effectiveness of recycling agents, influence of variables on hot recycling techniques, characterization of cold recycled mixtures, recycling of tar-rubber materials, and recycling of porous friction course (PFC) materials.

Effectiveness of Recycling Agents

More than 30 recycling agents are currently available. Not all of these may be suitable for Air Force purposes. It is suggested that a research program be initiated to determine which characteristics of recycling agents make them suitable for use under current mixture design procedures. From this study, recycling agent specifications may be developed for use in the update of the recycling manual. Table 21 shows that this priority A project would take two years to complete at a budget of $300,000.

TABLE 21. DETERMINING EFFECTIVENESS OF RECYCLING AGENTS

Priority: A
Time Allotted: 24 months
Personnel Requirements:
a. Professional: 2.0 man-years
b. Technical: 2.7 man-years
c. Support: 0.8 man-year
Budget: $300,000
Fiscal Year: 1982-1983

Influence of Variables on Characteristics of Hot Recycled Mixtures

This project would be designed to discover the effects of various field construction conditions on the behavior of hot recycled pavement mixtures. Some of these conditions might include poor aggregates, plant operations, and compaction efforts. This study would provide a realistic perspective on the performance to be expected of these materials. The program would require 12 months and $240,000 to complete (Table 22).

TABLE 22. DETERMINING INFLUENCE OF VARIABLES ON CHARACTERISTICS OF HOT RECYCLED MIXTURES

Priority: A
Time Allotted: 12 months
Personnel Requirements:
a. Professional: 0.7 man-year
b. Technical: 1.2 man-years
c. Support: 0.3 man-year
Budget: $240,000
Fiscal Year: 1984

Characterization of Cold Recycled Mixtures

The characterization of cold recycled mixtures is important to the development of rational mixture and pavement thickness designs. Properties that should be investigated include stability, permanent deformation, fatigue, thermal cracking, water susceptibility, aging, and compressive strength.

The laboratory performance of recycled asphalt pavements will give a strong indication of their expected field performance. The results of this research project will be included in the recycling manual update at the end of the total effort.

In addition, a review of available cold recycling equipment should be conducted. The purpose would be to determine the capability and appropriateness of application of the various machines.

For this study a facility that includes a standard asphalt laboratory would be needed. The organization may have to purchase additional equipment or modify existing equipment in order to perform some of the more specialized testing. Table 23 shows that this project is considered an A priority. It would take about 2.5 years to complete at a cost of $600,000.

TABLE 23. CHARACTERIZATION OF COLD RECYCLED MIXTURES

Priority: A
Time Allotted: 30 months
Personnel Requirements:
a. Professional: 1.8 man-years
b. Technical: 3.0 man-years
c. Support: 0.8 man-year
Budget: $600,000
Fiscal Year: 1983-1985

Recycling of Tar-Rubber Materials

Many Air Force pavements are surfaced with tar-rubber materials. It is suggested that a study be conducted to investigate the reuse of this material. It is probable that air pollution problems would be associated with the hot recycling of tar-rubber materials. Therefore, it is recommended that any research program first approach the problem from the standpoint of cold recycling processes.

Table 24 presents an estimated budget of $85,000 to be spent over a period of eight months. This is considered a high-priority project.

TABLE 24. FEASIBILITY STUDY ON RECYCLING TAR-RUBBER MATERIALS

Priority: A
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.4 man-year
b. Technical: 0.4 man-year
c. Support: 0.2 man-year
Budget: $85,000
Fiscal Year: 1985

Recycling of Porous Friction Course Materials

Many Air Force runways have open-graded mixtures for surface courses. While these pavements offer added skid resistance on runways, they are also known to cause problems. This is particularly true in Europe, where it has been reported that delaminations are occurring between the surface and base courses of PFC pavements.

It is suggested that a research project be undertaken to develop a method of recycling PFC materials. This is a high-priority study that should take about eight months to complete at a cost of about $65,000 (Table 25).

TABLE 25. DEVELOPMENT OF METHOD OF RECYCLING POROUS FRICTION COURSES

Priority: A
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.4 man-year
b. Technical: 0.4 man-year
c. Support: 0.2 man-year
Budget: $65,000
Fiscal Year: 1982

PORTLAND CEMENT CONCRETE RECYCLING AND RESURFACING

Because a large number of the pavements in the Air Force inventory are made of PCC, a research effort should be started to investigate recycling techniques that would make it possible to reuse this material. The use of PCC in recycling operations has included using it as aggregate for both asphalt and PCC and also as part of the econocrete concept.

Literature Review and Research Plan

This effort should begin with a literature review that would produce a statement on the state-of-the-art and on shortcomings in the existing

technology. A research plan directed toward correcting some of the deficiencies and implementing PCC recycling would then be developed. This project would cost approximately $50,000 and would require about 8 months (Table 26). Because it would present the Air Force with more pavement rehabilitation options, this project is rated as a B priority.

TABLE 26. LITERATURE REVIEW AND RESEARCH PLAN FOR PORTLAND CEMENT CONCRETE RECYCLING

Priority: B
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.8 man-year
b. Support: 0.2 man-year
Budget: $50,000
Fiscal Year: 1981

PAVEMENT RECYCLING IN CRITICAL MILITARY OPERATIONS

Pavement recycling could play a major role in national emergencies if it became necessary to upgrade abandoned airfields. Logistical problems with equipment and materials could be somewhat simplified. In addition, procedures for rapidly completing mixture designs, pavement designs, and construction could be developed to expedite the reconstruction of such airfields.

Expedient Recycling Techniques for Military Operations

The use of expedient construction operations has proven invaluable to the military in the past. The ability to recycle airfield pavements would add to the military's capability to provide critical facilities in time of need. Rules of thumb could be developed for mixture and pavement design, and techniques that would minimize construction time could be developed.

A project of this nature would entail gathering information on and then simplifying the current technology. Table 27 shows that this effort would take an estimated eight months and would require a budget of about $126,000.

Because this would be a mission-oriented project for the Air Force, it is given an A priority.

TABLE 27. DEVELOPMENT OF EXPEDIENT RECYCLING TECHNIQUES FOR MILITARY OPERATIONS

Priority: A
Time Allotted: 12 months
Personnel Requirements:
a. Professional: 0.7 man-year
b. Support: 0.3 man-year
Budget: $126,000
Fiscal Year: 1984

Recycling Equipment List and Capabilities

Coinciding with the study of expedient techniques should be an effort directed toward developing a list of readily available recycling equipment. The equipment would be listed by recycling technique and manufacturer, and the size, weight, and capabilities of each type of equipment would be given. With periodic updating, this list would provide an immediate reference for use during critical times. Table 28 shows that eight months and an estimated $63,000 would be required for this project.

TABLE 28. DEVELOPMENT OF RECYCLING EQUIPMENT LIST AND CAPABILITIES FOR CRITICAL MILITARY OPERATIONS

Priority: A
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.5 man-year
b. Support: 0.2 man-year
Budget: $63,000
Fiscal Year: 1984

PERFORMANCE MONITORING

As more airfields in the Air Force inventory are recycled, a program of monitoring their performance should be started. The evaluation should relate to the types of distress that the recycling operations were intended to correct. Information on mixture design, pavement design, construction techniques, and quality control obtained during this study may be included in the update of the recycling manual.

Evaluation of Recycled Airfield Pavements

A number of options for conducting this study are available. The tests may include pavement condition index ratings, structural adequacy tests, skid resistance tests, roughness ratings, and field core tests. These tests could be used in any combination to evaluate the success of recycling operations that were intended to correct specific types of distress. The pavement condition index rating, at least, should be applied to every recycling project. It is suggested that each project be monitored at a minimum of once every six months.

The Air Force has the option of selecting an organization to perform the evaluations. The Air Force could choose to do the data collection and analysis itself or to contract with another organization for this work. It is not recommended, however, that one organization collect the data and another analyze it, nor is it recommended that a number of organizations be involved in performing these evaluations.

Table 29 shows that this should be at least a four-year study and could probably be accomplished for $600,000. This cost estimate is based on the assumption that an organization other than the Air Force would evaluate four airfields biannually. Because field performance is the best measurement of material behavior, this is considered an A priority research project.

Ten-Year Review of Asphalt Pavement Recycling

It is recommended that the Air Force take a critical look at the success of asphalt-concrete recycling in fiscal year 1985. By this time, most of the nation's recycled pavements will have been in use for at least ten years.

TABLE 29. PERFORMANCE EVALUATION OF RECYCLED AIRFIELD PAVEMENTS

Priority: A
Time Allotted: 48 months
Personnel Requirements:
a. Professional: 1.2 man-years
b. Technical: 4.6 man-years
c. Support: 0.5 man-year
Budget: $600,000
Fiscal Year: 1982-1985

A review of civilian and military pavement recycling projects would give an overview of their performance. This project would require about $85,000 and six months to complete. It is considered an A priority as shown in Table 30.

TABLE 30. TEN-YEAR REVIEW OF PAVEMENT RECYCLING

Priority: A
Time Allotted: 6 months
Personnel Requirements:
a. Professional: 0.8 man-year
b. Support: 0.2 man-year
Budget: $85,000
Fiscal Year: 1985

OTHER CONSIDERATIONS

Topics that do not fit into any of the first five categories, but which do merit consideration, remain to be discussed. These research areas include the examination of cost and energy requirements, the study of improved methods and equipment for heating pavements, and the formulation of quality control specifications.

Cost and Energy Requirements

A consolidation of data on the cost and energy requirements of asphalt pavement recycling compared with those of conventional rehabilitation methods would be an important contribution to the current technology. These data would build the confidence of engineers and contractors alike in the value of pavement recycling and would give them a basis upon which to make cost estimates. Several studies of this sort are currently being conducted by other agencies. It is believed that the data gathered by these agencies would be useful to the Air Force. Therefore, once these research projects have been completed, the results could be compiled for use by Air Force pavement engineers.

This project rates a C priority (Table 31). If the Air Force were to fund this study, about eight months and $80,000 would be required.

TABLE 31. STUDY OF COST AND ENERGY REQUIREMENTS

Priority: C
Time Allotted: 8 months
Personnel Requirements:
a. Professional: 0.5 man-year
b. Support: 0.2 man-year
Budget: $80,000
Fiscal Year: 1984

Improved Methods and Equipment for Heating Pavements

A subject that has received minimal attention in the past is that of improving the methods and equipment used to heat pavement during surface recycling operations. The heating is currently accomplished by applying open flames to the pavement surface. Controls on temperature and depth of heating in this process are marginal.

Through the use of microwave and infrared heating techniques, it is possible to more accurately control pavement temperature and the depth to which the pavement is heated. While these methods are refined, they require an extraordinary amount of energy. Therefore, a research effort aimed at improving the efficiency of these operations is needed.

This type of research is probably best left to equipment manufacturers, who have the incentive to develop the required capability. Table 32 shows that this project rates a C priority and would take about 12 months and $125,000 to complete.

TABLE 32. DEVELOPMENT OF IMPROVED METHODS AND EQUIPMENT FOR HEATING PAVEMENTS

Priority: C
Time Allotted: 12 months
Personnel Requirements:
a. Professional: 0.7 man-year
b. Technical: 0.7 man-year
c. Support: 0.3 man-year
Budget: $125,000
Fiscal Year: 1985

Criteria for Formulation of Quality Control Specifications

As a follow-up of the specifications and quality control project listed under Implementation, a verification of the effectiveness of these procedures should be planned. An organization that has field testing capability would be required. The mobile laboratory would visit various recycling construction projects and implement the quality control procedures that have already been established. Any deficiencies in the procedures would be identified during these tests and could be corrected in the update of the recycling manual. This project is considered a B priority (Table 33). It would require approximately two years and $320,000 to complete.

TABLE 33. ESTABLISHMENT OF CRITERIA FOR FORMULATION OF QUALITY CONTROL SPECIFICATIONS

Priority: B
Time Allotted: 24 months
Personnel Requirements:
a. Professional: 1.4 man-years
b. Technical: 1.6 man-years
c. Support: 0.6 man-year
Budget: $320,000
Fiscal Year: 1983-1984

SUMMARY

There are several worthwhile research topics in the area of asphalt pavement recycling toward which the Air Force could direct its efforts. The major thrust of these efforts should be in the area of implementation, which would include the development of interim and long-term specifications and procedures. All of these topics have been designated priority A.

Other projects that could be sponsored by the Air Force would add to the advancement of the general state-of-the-art. However, these projects are not considered prerequisites for the implementation of recycling by the Air Force. These research topics have been rated priority B.

Priority C topics include those which would contribute to the general knowledge but which would probably best be left to other organizations. Some of these subjects have already been funded by the Air Force.

A suggested master plan for the total research effort is given in Table 34. This table summarizes the proposed research topics, priorities, effort levels, durations, and budgets. The plan is based upon a time span of four years. It should be stressed that the estimated budget is based upon cost data for spring 1981 and that standard Air Force policy for accounting for inflation has been followed.

TABLE 34. MASTER PLAN FOR PAVEMENT RECYCLING RESEARCH

Topics	Priority	Effort Level, Man-Years			Schedule, Fiscal Year							Duration, Months	Estimated Budget, Dollars
		Professional	Technical	Support	81	82	83	84	85	86	87		
Data Base	A	2.2	---	1.8								48	320,000
Implementation													
Training Packages	A	1.0	---	0.3								12	104,000
Pavement Thickness Design	A	0.6	---	0.2								8	68,000
Update of Manuals Based on Research Programs	A	1.0	---	0.3								12	134,000
Mixture Design for Asphalt Pavement Recycling													
Effectiveness of Recycling Agents	A	2.0	2.7	0.8								24	300,000
Influence of Variables on Characteristics of Hot Recycled Mixtures	A	0.7	1.2	0.3								12	240,000
Characterization of Cold Recycled Mixtures and Equipment	A	1.8	3.0	0.8								30	600,000
Recycling of Tar-Rubber Materials	A	0.4	0.4	0.2								8	85,000
Recycling Porous Friction Courses	A	0.4	0.4	0.2								8	65,000
Portland Cement Concrete and Resurfacing													
Literature Review and Research Plan	B	0.8	---	0.2								8	50,000
Pavement Recycling in Expedient Military Operations													
Expedient Recycling Techniques for Military Operations	A	0.7	---	0.3								12	126,000
Recycling Equipment List and Capabilities for Expedient Military Operations	A	0.5	---	0.2								8	63,000
Performance Monitoring													
Performance of Recycled Airfield Pavements	A	1.2	4.6	0.5								48	600,000
Ten Year Review of Pavement Recycling	A	0.8	---	0.2								6	85,000
Other Considerations													
Cost and Energy Requirements	C	0.5	---	0.2								8	80,000
Improved Methods/Equipment To Heat Pavements	C	0.7	0.7	0.7								12	125,000
Establish Criteria for Formulation of Quality Control Specifications	B	1.4	1.6	0.6								24	320,000

APPENDIX A

SAMPLE SPECIFICATIONS FOR SURFACE RECYCLING

ARRA BID SPECIFICATIONS FOR SURFACE RECYCLING*

SCOPE

The work covered by this section of the specifications consists of furnishing all labor, equipment, and materials and performing all operations in connection with heating, scarifying, leveling, compacting, and applying a recycling agent preparatory to receiving an asphalt concrete overlay.

CLEANING

Prior to commencing heater scarifying operations the pavement shall be cleaned of all loose material. Power brooms shall be supplemented when necessary by hand brooming and such other tools as required to bring the surface to a clean, suitable condition, free of deleterious material. Any required patching work shall be completed prior to beginning the process.

EQUIPMENT

1. The equipment used to heat and scarify asphalt surface shall be fueled by liquified petroleum gas. It shall fully meet the standards of the State and Local Bureau of Air Pollution Control. The combustion chamber shall be insulated, rear wheel positioned and equipped with burners rated at a minimum of 4400 watts (15,000 BTU's per hour). The machine shall be equipped with two rows of spring-equalized scarifier leveling rakes with removable teeth incorporating an automatic release for manhole and valve protection. A competent operating crew, including a service vehicle, shall be provided.

2. The equipment used to distribute and level the scarified material shall be approved paving machine equipped with an operating vibratory or oscillating heated screed. The machine must be capable of screeding the full width of scarified material. A competent operating crew shall be provided.

3. One 11 tonne (twelve 12 ton) or greater pneumatic-tired roller and operator shall be furnished to compact the scarified material. The contractor may furnish another type compactor of equal size if approved by the engineer.

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*The material presented here is taken directly from Reference 25.

4. One asphalt, cab-controlled, liquid spreader with operator shall be furnished to distribute the asphalt rejuvenating agent.

CONSTRUCTION DETAILS

A minimum of two heater units will be utilized in tandem so that the heat emitted and the rate of travel will achieve specified requirements. The number of additional heater units shall be determined by the contractor; however, only the scarifier rakes on the final heater unit of the series shall scarify. A minimum production of 1200 square yards (1000 m^2) per hour shall be required.

The existing asphalt surface shall be heated from 150 to 300 mm (6 to 12 inches) wider than the width to be processed. The temperature of the scarified material shall be 114°C (300°F) maximum when measured with a stick thermometer behind the scarifier.

The weight of existing asphalt surface has been estimated to be approximately 2300 kg/m^3 (144 pounds per cubic foot). On this basis, a minimum of 44 kg/m^2 (nine pounds per square foot) of existing surface shall be scarified to obtain a depth of between 19 and 25 mm (3/4 and 1 inch). If tests indicate that the material weighs either less than 2200 kg/m^3 (137 pounds per cubic foot) or more than 2400 kg/m^3 (151 pounds per cubic foot), the weight per area requirement will be adjusted accordingly by the engineer.

The scarified material shall be distributed and leveled only the width processed and be rolled immediately while it possesses sufficient heat to be properly compacted. Within eight (8) hours after compaction, an asphalt recycling agent selected from below shall be applied undiluted. The rate of application shall be determined by the engineer based on preconstruction laboratory analysis and adjustments for varying field conditions.

ASPHALT RECYCLING AGENTS

The asphalt recycling agent shall be composed of a petroleum base oil uniformly emulsified with water and shall conform to the physical and chemical requirements [listed in the accompanying table].

	Test Method		Requirements			
			Light Grade (Reclamite)		Medium Grade (Cyclogen MF)	
Tests on Emulsion	ASTM	AASHTO	Min	Max	Min	Max
Viscosity @ 25°C (77°F), SFS	D244-77	T59-74	15	85	15	85
Residue, %	D244-77(Mod)[1]	T59-74(Mod)[1]	60	--	60	--
Cement Mixing Test, %	D244-77	T59-74	--	2.0	--	2.0
Sieve Test, %	D244-77(Mod)[2]	T59-74(Mod)[2]	--	0.1	--	0.1
Particle Charge Test	D244-77	T59-74	positive		positive	
Tests on Base Oil[3]						
Original						
Viscosity @ 60°C (140°F) cST	D2170-76	T201-74	80	500	1000	4000
Flash Point COC, °F	D92-78	T48-74	400	--	450	--
Saturates, %[4]	D2007-75	- - -	--	30	--	28
Asphaltenes, %	D2006-70	- - -	--	1.5	--	0.0
PC/S Ratio	D2006-70	- - -	0.5	--	0.5	--
Maltenes Distribution Ratio $(PC + A_1)/(S + A_2)$[5]						
Test on Residue From RTF-C Oven Test @ 163°C (325°F)	D2872-77	T240-73				
Viscosity Ratio[6]	D2170-76	T201-74	--	3.0		2.5
RTF-C Oven Wt. Change, %	D2872-77	T240-73	--	6.5		2.0

1 ASTM D244 Modified Evaporation Test for percent residue is made by heating 50 gram sample to 149°C (300°F) until foaming ceases, then cool immediately and calculate results.

2 Test procedure identical with ASTM D2444 except that distilled water shall be used in place of 2% sodium oleate solution.

3 Values obtained on the emulsion's residue may vary slightly from the base oil.

4 ASTM D2006-70 can be used for the determination of saturates.

5 In the Maltenes Distribution Ratio Test by ASTM Method D2006-70
PC = Compounds A_1 = First Acidaffins
A_2 = Second Acidaffins S = Saturates

6 $$\text{Viscosity Ratio} = \frac{\text{RTF-C Viscosity A 60°C (140°F), cST}}{\text{Original Viscosity @ 60°C (140°F), cST}}$$

PROTECTION OF EXISTING IMPROVEMENTS

Since high temperatures are required in the surface recycling operation, Contractor shall exercise care against possible injury or damage to existing improvements. Contractor shall protect all existing curbs, gutters, trees, shrubbery and other improvements from damage. The smaller parkway trees shall be protected by shields and overhanging trees may be sprayed with water to inhibit damage. No machine with an open flame exhaust will be permitted. Existing improvements damaged by the Contractor shall be repaired or replaced to the satisfaction of the City Engineer at no cost to the City.

AIR QUALITY PRESERVATION

Contractor shall minimize the escaping of solids into the air by either the machine or burning of pavement during the operation. The machine shall be operated under a permit of the local Air Quality Control District. In the event that an emission problem develops, it may be necessary to remove the contaminate by cold planing. No additional compensation will be allowed for any steps required to reduce emissions.

TESTING AND CONTROL

The bidding agency will employ the services of a qualified laboratory to obtain the following data. Abson recovery tests shall be made on representative cores prior to construction to obtain asphalt penetration (ASTM D5) and to determine results of treating binder with varying quantities and grades of recycling agents per attached specifications. No work shall be undertaken until the laboratory report has been approved by the Engineer. The cost of testing and preparation of reports shall be included in the cost per square yard for surface recycling. The number of cores required shall not exceed one (1) per 8360 m^2 (10,000 square yards) of treated pavement.

MEASUREMENT AND PAYMENT

Cost of pretreatment, including cleaning, heating, scarifying, leveling, and compacting, but excluding recycling agent, shall be paid for in square yards

of surface area covered regardless of the number of operations involved to meet these specifications.

Asphalt recycling agent paid for by weight shall be weighed on sealed scales, regularly inspected by State Bureau of Weights and Measures, or may be measured in some other approved manner. A load slip shall be furnished for each vehicle weighed and slip shall be delivered to the Engineer at point of delivery of material. Asphalt concrete overlay required shall not be paid for under this section.

NCHRP GUIDE SPECIFICATION FOR PLANING OPERATIONS*

1.0 <u>DESCRIPTION</u>

This work shall consist of planing or leveling a pavement by removing imperfections and bringing the surface to the required smoothness or cross-section as indicated in the plans and specifications or as directed by the engineer. (This planing operation is often performed in preparation of a surface treatment or seal coat.)

2.0 <u>MATERIALS</u>

No additional materials will be utilized in this operation.

3.0 <u>EQUIPMENT</u>

Heaters, cold planers or hot milling machines shall be specifically designed and built exclusively for planing, milling or shaving a pavement. The equipment shall be self-propelled and have a means of heating or milling to plane the surface to predetermined grade. The equipment shall have a history of successful operation on similar work completed prior to this contract or equipment proven through test results.

Heater planer units shall consist of burners of a type specifically designed for this purpose of pavement heating and shall be capable of producing 3.0 to 5.0 million watts (10 to 17 million BTU's per hour). Heat shall be applied under an enclosed or shielded hood. The surface of the old pavement shall not be heated in excess of 205°C (400°F).

The equipment shall meet the standards of the State and Federal Air Pollution Control laws.

Hot and cold milling units shall consist of a cutting drum or edge with replaceable bits, teeth, or edge. Drum lacing patterns or edges may provide a grooved or smooth surface finish as selected by the engineer. The machine shall be capable of operating at speeds from 1.5 to 15 m (5 to 50 feet) per minute and designed to cut 0 to 75 mm (3 inches) deep to predetermined grade

*The material presented here is taken directly from Reference 6.

in one pass. A dust suppression system shall be standard equipment on this equipment. The equipment shall meet the standards of the State Air Pollution Control laws.

4.0 CONSTRUCTION

The nature and condition of the equipment, and the manner of performing the work, shall be such that the pavement is not torn, gouged, broken, or otherwise damaged by the leveling or planing operation.

Sufficient passes or cuts shall be made so that all irregularities or high spots are eliminated and that the pavement surface has been leveled to the desired grade as indicated on the plans and specifications.

Whenever a pavement is to be resurfaced, a keyway one inch in depth shall be cut along the gutter line to eliminate feathering the edge of the new surface. The width of this keyway shall be 1.2 m (4 feet) unless directed by the engineer.

The contractor shall provide all necessary labor, materials, and equipment to load the asphalt cuttings into dump trucks supplied and operated by owner (this could be changed to: into dump trucks supplied by him and hauled to a disposal area designated by the engineer).

The operation shall be planned so as to be safe for persons and property adjacent to the work, including the travelling public. As a precaution overhanging trees shall be trimmed in advance of this operation to a 2.7 m (9 ft) maximum clearance. Parkway trees may be protected from heat damage by individual shielding and/or water spray as deemed practical by the engineer. Any heat damage to structures, trees and shrubs will be repaired or replaced at no additional cost.

5.0 MEASUREMENT

Asphalt pavement planing performed and provided above shall be measured in-place and is computed in square yards.

6.0 BASIS OF PAYMENT

The accepted quantities of planing will be paid at the contract unit price per square yard.

7.0 SEASONAL AND TEMPERATURE VARIATIONS

Surface planing shall be performed with heater-planers only when the air temperature as measured in the shade is above 7°C (45°F).

NCHRP GUIDE SPECIFICATION FOR HEATER-SCARIFICATION OPERATIONS*

1.0 DESCRIPTION

This work shall be a part of a multistep process of asphalt surface rehabilitation that consists of softening the existing flexible pavement with heat and thoroughly stirring or tumbling the mixture; applying an asphalt recycling modifier as required; and placing a chip seal or overlay as required.

2.0 MATERIALS

2.1 Recycling Modifier: The asphalt modifier shall be specified by the engineer prior to letting of the contract and shall conform to a type as specified.

2.2 Aspahlt: The type and grade of asphalt cement for the seal coat and/or asphalt concrete shall be specified by the engineer prior to letting of the contract.

2.3 Aggregates: The type and grade of aggregate for the seal coat and/or asphalt concrete shall be specified by the engineer prior to letting of the contract.

2.4 Asphalt Concrete: The mix for the asphalt concrete shall be designed in accordance with the agency's standard method of mix design.

3.0 EQUIPMENT

3.1 Heater-Scarifier: The equipment for heating and scarifying shall be of a type that has operated successfully on similar work completed prior to the award of this contract or equipment proven through test results.

Heater-scarification uses shall consist of burners of a type specifically designed for the purpose of pavement heating and shall be capable of producing 3.0 to 5.0 million watts (10 to 17 million BTU's per hour). Heat shall be applied under an enclosed or shielded hood. The surface temperature of the old pavement shall not be heated in excess of 190°C (375°F).

The equipment shall meet the standards of the State Air Pollution Control laws.

*The material presented here is taken directly from Reference 6.

Scar'fying shall be accomplished with pressure-loaded rakes or scarifiers. The scarifying unit may be equipped to scarify and move away from gutter aprons a 12.5-mm by 1.2-m (1/2-inch by 4-foot) path of existing material. Additionally the scarifier shall be of a type to insure continuous and undiminished pavement contact without damaging manholes and valve boxes.

The leveling unit shall be capable of distributing the heated and scarified material over the width being processed so as to produce a uniform cross section. The leveling device shall have the capability of windrowing excess material to one side for removal when necessary.

The heater scarification operation shall be between 800 to 12,500 m^2 (1,000 to 15,000 square yards) per hour.

3.2 Distributor: The distributor shall conform to specification and shall be capable of applying a continuous and uniform application of recycling modifier or asphalt.

3.3 Aggregate Spreader: The aggregate or chip spreader shall conform to specification and shall be capable of distributing a continuous and uniform amount of aggregate.

3.4 Asphalt Concrete Construction Equipment: Equipment for batching, mixing, hauling and placing asphalt concrete shall conform to specification.

3.5 Rollers: A penumatic tired roller or steel wheel roller conforming to specification and with a gross weight of 9 to 11 tonnes (10 to 12 tons) is suitable for compaction of the heater scarified mixtures. Pneumatic tired rollers shall be used for seal coat aggregate embedment.

4.0 CONSTRUCTION

4.1 Surface Preparation: The pavement surface to be heater scarified shall be cleaned of trash, debris, earth, or other deleterious substances present in sufficient quantity to interfere with the work to be performed.

4.2 Application of Recycling Modifier: A recycling modifier or other asphalt material shall be applied to the existing pavement surface at a rate to be determined by the engineer in the leveling or profiling operation. The type, amount, and need for the modifier or asphalt material shall be determined by the engineer.

4.3 Heating and Scarifying: The pavement surface shall be evenly heated and remixed to a depth of between 0.015 to 0.020 m (0.05 to 0.07 ft) by a continuously moving surface heater scarifier machine. At least 90 percent of the aggregate shall be remixed by spinning or tumbling. The surface temperature of the old pavement shall be below 205°C (400°F) during heating and the heated material shall have a temperature in a range between 105 to 127°C (220 to 260°F) as measured immediately behind the heater scarifier. The remixed layer shall be uniformly and evenly heated throughout. No uncontrolled heating, causing differential softening of the upper surface, shall be permitted. The asphalt binder shall not be carbonized in excess of 0.10 percent. The heating operation shall extend at least 100 mm (4 inches) beyond the width of the scarification on both sides.

When a heater-scarifier pass is being made adjacent to a previously placed mat, the longitudinal joint shall extend at least 50 mm (2 inches) into the previously placed mat.

Note: When the surface to be scarified is to have an overlay of new pavement placed thereon, the scarified material adjacent to any concrete structure can be planed or regraded to provide a uniform cross-slope. The excess material may be distributed and compacted as a leveling course over the adjoining scarified surface or removed from job site depending upon the finished grade design contour. Excess material or oversized aggregate dislodged by the planing or remix operation and too large to be covered by the overlay shall be removed and disposed of by the contractor at his expense.

4.4 Leveling: Following the heater scarifier and before overlay installation, a leveling device reduces ridge buildup present from heavy scarification of soft mixtures. Material processed by the leveling device should be monitored to assure leveling of grooved and loose strike-off. The temperature of the scarified mix as it leaves the leveling device shall be 79°C (175°F).

An alternate leveling operation may be necessary when an aggregate chip seal has been specified. Following scarification and before compaction an oscillating or vibrating device shall spread and distribute the loosened mix. Rolling may be required to compact oversized aggregate and finish the mat, closing the voids.

4.5 Aggregate Seal Coat: An aggregate seal coat shall be applied as required by the plans and by methods described in Item ___.*

4.6 Asphalt Concrete Overlay: Within five minutes after reshaping the scarified mix and before the temperature drops below 66°C (150°F), a uniform layer of new surface course material shall be applied by a vibratory screed or strike-off assembly. The machine shall be capable of spreading and finishing the surface in lase widths to the specified section and thickness. The vibratory screed or strike-off assembly shall effectively produce a finished surface of the required uniform slope and texture without tearing, shoving or gouging the mix. The controls section of the screed shall be adjustable to taper the finished surface to the height of the gutter apron. The surface shall be compacted to the desired density.

Note: An alternate to this method is possible with certain equipment. A single unit or item of equipment can heat-scarify, add modifier or asphalt, and mix the old scarified pavement with new asphalt to allow this option if desirable.

5.0 MEASUREMENT

The heater-scarification process will be measured in place and the area computed in square yards. Additional bituminous mix, aggregates, and asphalt shall be paid for in accordance with standard specification. Modifiers shall be paid for by weight and shall be weighed on sealed scales, regularly inspected by State Bureau of Weights and Measures, or may be measured in some other approved manner.

6.0 BASIS OF PAYMENT

The accepted quantities of heater-scarification will be paid at the contract unit price per square yard.

7.0 SEASON AND TEMPERATURE VARIATIONS

Heater-scarification shall be performed only when the air temperature as measured in the shade is above 7°C (45°F).

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*To be developed by the organization using the specifications.

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APPENDIX B

SAMPLE SPECIFICATIONS FOR COLD-MIX RECYCLING

MAINE PROVISIONS FOR COLD RECYCLING*

Washington
RF-030-1(8)
October 27, 1975

SPECIAL PROVISION

SECTION 306

RECLAIMED MATERIAL FOR STABILIZED BASE

306.01 Description: This work shall consist of scarifying and pulverizing existing bituminous pavement and underlying aggregate from the old roadway to provide material for a stabilized base course as shown on the plans and as directed by the Engineer.

306.02 Material: Material shall consist of the existing bituminous surface, and a designated portion of the underlying base aggregate, mixed as directed using approved pulverizing and mixing equipment.

CONSTRUCTION REQUIREMENTS

306.03 Shoulders: The existing shoulders shall be excavated to the designated lines and grade and the aggregate subbase shall be placed up to at least the adjacent pavement elevation before the pulverizing operation is started.

306.04 Pulverizing: The existing pavement shall first be broken by scarifying with conventional equipment such as a grader-mounted or bulldozer-mounted ripping or scarifying device. After breaking the existing pavement in this manner, the specified depth of pavement and underlying aggregate shall be windrowed and further processed in place by a travelling hammermill or other approved pulverizing equipment until all material is reduced to a maximum size specified. The maximum size aggregate shall be that which will pass a 63-mm (2-1/2-inch) square mesh sieve.

During nonworking hours, the Contractor shall leave the material being processed in a safe condition to carry traffic.

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*The material presented here is taken directly from Reference 45.

The Contractor's attention is directed to the provisions of subsection 107.23, Safety and Accident Prevention, in respect to flying rocks from the pulverizing process.

306.01 Use of the Material: Prior to placing the pulverized and mixed material in its final position, the underlying base material of the traveled way shall be shaped and compacted to a tolerance of 25 mm (1 inch) above or 25 mm (1 inch) below the required grade and cross section. The compaction in the top 150 mm (6 inches) shall not be less than 95 percent of the maximum density determined in accordance with the provisions of subsection 304.04 of the Standard Specifications.

The pulverized and mixed material shall then be bladed onto the prepared underlying base material and shaped and graded within reasonably close conformity with the lines, grades and typical cross sections as shown on the plans or established by the Engineer. Spreading, compacting and fine grading shall be in accordance with the applicable portions of subsection 304.04 of the Standard Specifications.

The completed surface of the stabilized base course shall be shaped and maintained to a tolerance, above or below the required cross sectional shape, of 9.5 mm (3/8 inch).

306.10 Method of Measurement: Reclaimed stabilized base will be measured by the square yard of processed material of the required depth, measured in place in its final locations as shown on the plans or otherwise designated by the Engineer.

306.11 Basis of Payment: Reclaimed stabilized base will be paid for at the contract unit price per square yard for the depth shown on the plans, which price shall be full compensation for furnishing all equipment; for scarifying and pulverizing the pavement and underlying aggregate; for shaping and compacting the underlying base material; and for all spreading, fine grading, and compacting the material in place.

Payment will be under:

Pay Item		Pay Unit
306.121	Reclaimed Stabilized Base	S.Y.

WISCONSIN PROVISIONS FOR COLD RECYCLING*

Section 205: Roadway and Drainage Excavation

205.3.5 is supplemented to provide that any additional material required for reshaping of existing ditches shall be borrow excavation.

205.4 is amended to provide that no measurement or payment for overhaul will be made.

Section 211: Preparation of Foundation

211.1 is supplemented to include the scarification and pulverization of the surface of the existing roadway in reasonably close conformity with the plans and these specifications, immediately prior to the application of a prime coat and surface course.

211.1 is further supplemented to include the addition of an asphalt emulsion and a chemical for dispersing asphalts.

211.2 is supplemented to provide that where any existing base material is less than 150 mm (6 inches), additional materials required to be added to the pulverized base material in order to reshape the roadway shall meet the requirements of Section 304, Gradation No. 1 or No. 2.

211.2 is further supplemented to provide that bituminous materials shall meet the requirements of Section 401.3.6 for the type of asphalt listed in the bid item.

The chemical additive shall meet the following requirements:

The chemical shall be SA-1, manufactured by Saunders Petroleum Company (303)352-0467, P.O. Box 129, Greeley, Colorado 80631.

The chemical additive will be diluted in such proportion with water that when applied to the scarified asphaltic concrete it will disperse such asphalts and tar residues so that they may be reused as the bonding agents with the aggregate. It must also thoroughly and completely disperse newly applied asphalt cements into the sands and granular materials when applied simultaneously with or subsequent to the application of the asphalts to such material. It must not leave injurious chemical residues or must not damage plant life. It must be completely water soluble and disperse readily when subjected to modified agitation. When introduced to water it must not leave an oil film on the surface and when diluted, 1 part to 1,000 parts of water, it should have a pH not less than 1.8 nor greater than 1.9.

*The material presented here is taken directly from Reference 7.

211.3 is supplemented to provide that the equipment necessary to perform the work described in this section shall be capable of scarifying, pulverizing, mixing, and spreading the materials on the roadway. Hauling of materials to a separate site for pulverizing will be permitted in lieu of pulverizing the materials on the roadway, but no additional payment for the haul of the material will be made. A water truck, 23,000-litre (6,000-gallon) minimum capacity, will also be required to apply the chemical additive solution.

211.4.5 is supplemented as follows:

The road including the bituminous surface shall be scarified to the depth and width shown. The scarified material shall be pulverized so that 100 percent shall pass a 75-mm (3-inch) sieve and not more than 5 percent of the material will be retained on a 50-mm (2-inch) sieve. The pulverized material shall be blended such that the pulverized bituminous surface and base material shall form a homogeneous mass.

The pulverized material shall be moistened if necessary and compacted to a density of not less than 95 percent of the maximum density determined in accordance with AASHTO T99, Method C, and in accordance with Section 646.

Where specified to be added, the rate of application of emulsified asphalt shall be determined by the Engineer. An approximate rate of 6.78 litres per square meter (1-1/2 gallon per square yard) is typical. The mixture shall be constructed as provided in Section 303.

Where specified to be added, the rate of application of the chemical additive will be determined by the Engineer.

Approximate rates of application are as follows and are based upon thickness of the existing asphaltic concrete:

Thickness of Asphalt	Amount of Solution Per Foot-Mile 491 m^2 (587 yd^2)	Additional Amount of Solution Per Foot-Mile in Clayey or Silty Bases
50 mm (2 inches)	3780 litres (1000 gallons)	5670 litres (1500 gallons)
100 mm (4 inches)	5670 litres (1500 gallons)	5670 litres (1500 gallons)
150 mm (6 inches)	7560 litres (2000 gallons)	5670 litres (1500 gallons)
200 mm (8 inches)	9450 litres (2500 gallons)	5670 litres (1500 gallons)

The proportion of chemical additive to water in the solution is approximately 3.78 litres (1 gallon) of chemical additive (SA-1) to 3780 litres (1000 gallons) of water. The mixture shall be constructed as provided below:

1. As soon as the scarification has been completed, the application of the chemical shall immediately follow. Water is essential in the breakdown of asphaltic concrete and after the initial application of the chemical, additional water may be needed contingent on the speed of the reaction and weather conditions.

2. Following the application of the chemical, mechanical assistance shall be provided in the form of a sheepsfoot roller or steel wheeled roller, pulva mixer, or other approved equipment, the same as in pulverizing pavement without the chemical additive.

3. Once a breakdown of the asphaltic concrete is underway, the underlying base course and any borrowed granular material shall be mixed with the recycled asphaltic concrete. This process shall be continued until a uniform mixture is accomplished.

4. If emulsified asphalt is to be applied in addition to the chemical, it shall be done following completion of the above uniform mixture and the mixture shall then be constructed as provided in Section 303.

211.5 is amended to provide that the scarifying and pulverizing will be measured by the square yard.

Additional base materials where required shall be measured and paid for as provided in Section 304.

Water for moisture or the chemical additive solution will be measured by the 3780 litres (1000 gallons).

Emulsified asphalt will be measured and paid for as provided on Section 303.

Chemical additive (SA-1) will be measured by the gallon before mixture into the solution.

211.6 is amended to provide that the accepted quantities of Preparation of Foundation for Bituminous Paving determined as provided above will be paid for at the contract unit price per square yard, which price and payment will be full compensation for the work in this section.

211.6 is further amended to provide that the accepted quantities of chemical additive will be paid for at the contract unit price per gallon, which price and payment will be full compensation for the material and work involved.

211.6 is further amended to provide that the accepted quantities of water or water-chemical additive solution measured as determined above will be paid for at the contract unit price per 3780 litres (1000 gallons) (MG), which price and payment will be full compensation for the water, labor, and equipment necessary to complete the work in this section.

The following bid items are added to the Schedule of Bid Items:

Item No.	Item	Unit
21103	Preparation of Foundation for Bituminous Paving (Scarifying and Pulverizing)	Square Yard
21104	Chemical Additive	Gallon
21105	Water	MG

Section 303: Asphalt Stabilized Base Course

303.6.3 is supplemented to provide that asphalt furnished for treating pulverized aggregates shall be measured for payment by the gallon in accordance with the pertinent provisions set forth in subsection 401.3.3.

303.7 is supplemented to provide that asphalt furnished as provided above will be paid for at the contract price per gallon, which price shall include all work and equipment necessary to mix the asphalt with the pulverized aggregates.

Section 304: Crushed Aggregate Base Course

304.2.6 is supplemented to require that the gradation for aggregates to be used on the top portion of shoulders as shown in the typical sections shall meet the following:

Sieve Size	Percentage by Weight Passing Gradation A for Shoulders Crushed Gravel
25 mm (1 inch)	100
12.5 mm (1/2 inch)	35-90
4.75 mm (No. 4)	20-75
0.45 mm (No. 40)	5-40
0.075 mm (No. 200)	0-20

304.2.6 is further supplemented to require that the gradation for aggregate to be used for Grading B shall conform to the requirements of subsection 209.2, Grade 2.

304.5 is supplemented to provide that the crushed aggregate base course shall be compacted in accordance with the requirements for Special Compaction and in accordance with Section 646.

NCHRP GUIDE SPECIFICATION
FOR IN-PLACE RECYCLING OF EXISTING ASPHALT SURFACE AND/OR EXISTING BASE (SUBBASE) WITHOUT CHEMICAL STABILIZATION*

1.0 Description

This work shall consist of pulverizing the existing asphalt surface and/or existing base (subbase); mixing additional aggregate (as required); placing and compacting to the lines, grades, and dimensions shown on the plans and/or as specified in the special provisions. (This work shall not include the use of a chemical stabilizer such as lime, portland cement, or asphalt.)

2.0 Materials

2.1 Recycled Aggregate: The material shall consist of a mixture of existing asphalt pavement and materials lying under the pavement. Existing asphalt pavement and/or stabilized bases shall be ripped and pulverized so that 100% will pass the 37.5-mm (1-1/2-inch) sieve.

2.2 New Aggregate: The new aggregate shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone screenings, mineral dust, or a combination of any of these materials meeting the gradations and quality requirements of the agency.

2.3 Asphalt Primer: The asphalt primer, if used, shall be MC-30, MC-70, MC-250, or RC-70 as specified by the engineer. The asphalt primer shall meet the requirements of AASHO Specifications M81 or M82 (ASTM Specifications D2028 or D2027) for the material selected.

3.0 Equipment

As many as necessary of the following named pieces of equipment shall be used to complete the specified work: scarifiers; pulverizing equipment; rotary mixers or travel plants; motor graders; windrow devices; aggregate spreaders; power brooms or power blowers, or both; self-propelled vibratory or steel-tired tandem and pneumatic-tired rollers capable of attaining the required density; a pressure distributor designed and operated to distribute the asphaltic material in a uniform spray without atomization; equipment for heating the asphaltic material; and a water distributor. Other equipment may be used in addition to, or in lieu of, the specified equipment when approved by the engineer.

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*The material presented here is taken directly from Reference 6.

4.0 Construction

4.1 Scarification and Pulverization: The old pavement shall be scarified and pulverized to the depth shown on the plans. Scarification and pulverization can be accomplished in a single pass operation to a depth of about 100 to 150 mm (4 to 6 inches) or a multistep process can be utilized which consists of scarification, windrowing and pulverization. All material shall be pulverized such that 100% passes the 37.5 mm (1-1/2-inch) sieve.

4.2 New Aggregate: It may be desirable from a gradation or thickness standpoint to blend two or more aggregates which shall result in a combined gradation meeting the specifications for the finished material. The materials shall be mixed on the roadbed or on some other approved area off the roadbed by mixing machines or by blade mixing.

4.3 Application of Asphalt Primer: The previously prepared roadway surface prior to the start of the placing operations shall be primed, if needed, with one of the asphalt primers shown on the list of bid items. The asphalt primer shall be applied in accordance with acceptable engineering practice.

Spreading and Compaction: The unstabilized pulverized material shall be uniformly spread over the area to such depths that the material will compact to the specified thickness. This mixture shall be spread for compaction from a large windrow. It shall be bladed from the windrow in a succession of thin layers to a uniform cross section of specified thickness.

After the mixture is spread as specified, each layer shall be thoroughly and uniformly compacted. Test holes shall be dug at specified intervals to determine the compacted thickness of the layers being placed. Areas in which a deficiency of more than 13 mm (0.5 inch) compacted thickness is indicated shall be reworked with added mixed material sufficient to increase the layer to the depth specified. All irregularities that develop in the surface shall be corrected by blading. Blading and compaction shall continue until the surface is true to grade and cross section. Final compaction shall be obtained by rolling with a steel-tired tandem roller. The specified in-place density shall be obtained.

5.0 General

5.1 Samples: Samples of all materials proposed for use shall be submitted by the contractor to the engineer. The material shall not be used until it is approved by the engineer.

Sampling of asphaltic materials shall be in accordance with the latest revision of AASHTO Designation T40 (ASTM Designation D1940). Sampling of mineral aggregate shall be in accordance with the latest revision of AASHTO Designation T2 (ASTM Designation D75).

5.2 Methods of testing:

(1) Asphaltic materials will be tested by the methods of tests of the American Association of State Highway and Transportation Officials (AASHTO). If an AASHTO method of test is not available, the American Society for Testing and Materials (ASTM) method will be used.

(2) Mineral aggregates will be tested, as designated in the detailed requirements of these specifications, by one or more of the following AASHTO methods of test. If an AASHTO method of test is not available, the ASTM method will be used.

Characteristic	Method of Test	
	AASHTO	ASTM
Abrasion of Coarse Aggregate, Los Angeles Machine	T96	C131
Sieve Analysis, Fine and Coarse Aggregates	T27	C136
Unit Weight of Aggregate	T19	C29
Sand Equivalent	T176	C2419

5.3 Weather: Asphalt shall not be applied when the air temperature in the shade is less than 10°C (50°F) unless otherwise permitted by the engineer. Work shall be suspended during rain.

5.4 Traffic Control: Traffic shall be directed through the project with warning signs, flagmen, and pilot trucks or cars in a manner that provides maximum safety for the workmen and traffic and the least interruption of the work.

Traffic shall be kept off of freshly sprayed asphalt.

5.5 Safety: Safety precautions shall be used at all times during the progress of the work. As appropriate, workmen shall be furnished with hard hats, safety shoes, asbestos gloves, respirators, and any other safety apparel that will reduce the possibility of accidents. All Occupational Safety and Health Act Requirements shall be observed.

6.0 Measurement

(1) Scarification and Pulverization: The area scarified and pulverized shall be measured in place and the area calculated in square yards.

(2) Asphalt Primer: Total number of gallons at 15.5°C (60°F) or tons of material placed.

(3) New Aggregate: Total number of tons of new mineral aggregate incorporated into the work.

(4) Mixing, Placing, and Compacting: Total square yards of material placed.

(5) Water: Total number of gallons of water incorporated into the work.

7.0 Basis of Payment

The quantities described above shall be paid for at the contract unit price bid for each item. Payment will be in full compensation for furnishing, hauling, and placing materials for mixing, for rolling, and for all labor and use of equipment, tools, and incidentals necessary to complete the work in accordance with these specifications.

In adjusting volumes of asphaltic material to the temperature of 15°C (60°F), ASTM Designation D1250, ASTM-IP Petroleum Measurement Tables, will be used.

NOTES TO THE ENGINEER

The foregoing specifications are recommended for use under what may be termed average conditions. It is realized, however, that no single standard specifications will cover satisfactorily all variations in local conditions that may prevail for individual jobs. Before adopting these specifications verbatim, the engineer should give particular attention to local conditions and make the changes as necessary.

Prior to letting the contract the engineer should select the particular type of asphaltic materials he wishes to use, deleting the requirements for all other materials shown in these specifications.

The gradations of mineral aggregates should be selected for those usually specified in this type of construction by the agency. If it is necessary to import aggregates to adjust the grading of the material in place on the roadbed, the contractor should be so informed before he is awarded the contract.

The grading of the aggregate that must be imported and the locations where adjustments are necessary should be generally indicated either in the specifications or on the plan in order that the contractor will be in a position to make an intelligent bid.

NCHRP GUIDE SPECIFICATION
FOR IN-PLACE RECYCLING OF EXISTING ASPHALT SURFACE AND/OR
EXISTING BASE (SUBBASE) EMPLOYING LIME STABILIZATION*

1.0 Description

This work shall consist of pulverizing and mixing in-place material, new aggregate (as required), lime, and water and spreading and compacting the mixture to the lines, grades, and dimensions shown on the plans and specified in these special provisions.

2.0 Materials

2.1 Recycled Aggregate: The material to be treated shall consist of a mixture of existing asphalt pavement and the material lying under the pavement. Existing asphalt pavement and stabilized bases shall be ripped and pulverized so that 100% will pass a 37.5-mm (1/2-inch) sieve.

2.2 New Aggregate: The new aggregate shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone screenings, mineral dust, or a combination of any of these materials meeting the gradation and quality requirements of the agency.

2.3 Lime: Lime shall be a commercial, dry, hydrated lime conforming to the definitions in ASTM Designation C51 or, if permitted by the engineer, quick-lime may be used.

The hydrated lime shall contain not less than 85 percent of calcium hydroxide, $CA(OH)_2$, as determined by ASTM C025. Quick-lime shall contain not less than 90 percent calcium oxide (CaO).

A certificate of compliance with specifications shall be supplied with each delivery of lime and shall be submitted to the engineer with a certified copy of the weight of each delivery.

2.4 Asphalt Primer and Curing Membrane: The asphalt primer, if used, shall be MC-30, MC-70, M-250, or RC-70 as specified by the engineer. The asphalt primer shall meet the requirements of ASTM Specification D2027 or D2028.

The curing seal or membrane shall be an emulsified asphalt selected by the engineer and shall meet ASTM Specification D977 or D2397.

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*The material presented here is taken directly from Reference 6. Where blanks appear, the using organization must develop the required information in order to use the specifications.

3.0 Equipment

The equipment used for pulverizing the asphaltic material shall (1) be capable of sliding or lifting the said material above the roadway so that the material is suspended in midair during the pulverization, and (2) have a cross shaft rotor with pulverizing blades capable of revolving at 750 RPM, or more, during the pulverizing process.

If the equipment the contractor plans to use does not conform to the above, the engineer shall require a demonstration to prove the equipment capable of pulverizing the asphaltic material to the required size before permitting it on the job.

4.0 Construction

4.1 Scarification and Pulverization: The old pavement shall be scarified and pulverized to the depth shown on the plans. Scarification and pulverization can be accomplished in a single pass operation to a depth of about 100 to 150 mm (4 to 6 inches) or a multi-step process can be utilized which consists of scarification, windrowing, and pulverization. All materials shall be pulverized such that 100% passes the 37.5-mm (1-1/2-inch) sieve.

4.2 New Aggregate: It may be desirable from a gradation, plasticity, or thickness standpoint to blend two or more aggregates which shall result in a combined gradation meeting the specifications for the finished materials. The materials shall be mixed on the roadbed or on some other approved area off the roadbed by mixing machines or by blade mixing.

4.3 Mixing: Hydrated lime shll be added at the rate of ______________ pounds per square foot of material to be treated. If quick-lime is used the quantity may be 15% less than the quantity required for hydrated lime.

Lime treated material shall not be mixed or spread while the atmospheric temperature is below 1.7°C (35°F), or when conditions indicate that the temperature may fall below 1.7°C (35°F) within 24 hours.

Lime may be spread in either a slurry or dry state at the option of the contractor.

If the lime is spread dry it shall be prevented from blowing by adding water or other suitable means elected by the contractor.

Lime shall be spread by equipment which will uniformly distribute the required amount of lime, and the rate of lime spread per square foot of

blanket shall not vary more than 10 percent from the designated rate, unless otherwise approved by the engineer.

No traffic other than the mixing equipment will be allowed to pass over the spread lime until after completion of preliminary mixing, except for water trucks.

The lime treated material shall be ____inches thick, when compacted. After the lime has been spread, the lime, other material, and water shall be thoroughly mixed to the full depth of the lift, lightly rolled, and allowed to cure at least overnight. The preliminary and final mixing may be done with any equipment selected by the contractor.

Final mixing or remixing operations shall continue until the material is free of streaks or pockets of lime and the mixture is uniform; and (1) there are no pieces of untreated clay in excess of 25 mm (1 inch) in diameter, and (2) 90% of the asphaltic material shall pass a 25-mm (1-inch) or 37.5-mm (1-1/2-inch) screen.

Nonuniformity of color reaction when the treated material is tested with the standard phenophthalein alcohol indicator will be considered evidence of inadequate mixing.

4.4 Spreading and Compaction: The treated mixture will be spread to the required planned width, grade, and cross section.

Lime treated material shall be compacted to not less than ______percent, as determined by AASHTO T99, within 48 hours after mixing.

Initial compaction shall be by means of segmented wheel rollers. Final compaction shall be by means of either the segmented roller or pneumatic tired rollers. Minor indentations may remain in the surface of the finished material after final trimming and rolling.

In the event the plans call for more than one lift of lime-treated material, the lower lift shall be ____inches thick when compacted and shall be compacted to not less than ___percent, as determined by AASHTO T99, provided, however, a fluff of approximately one inch in thickness shall be created on the top of the lower lift before the material for the upper lift is added.

Each layer of lime-treated material, regardless of its thickness, may be compacted in one layer.

4.5 Curing: The surface of the lower layer of lime-treated material shall be kept moist until covered by a subsequent layer of the material to be lime-treated.

The top layer of lime-treated material shall be kept moist until a curing seal or final surfacing is added. The curing seal shall consist of a mixing type asphaltic emulsion.

Curing seal shall be applied at a rate between _____and _____gallons per square yard of surface, the exact rate to be determined by the engineer.

5.0 Measurement

(1) Scarification and Pulverization: The area scarified and pulverized shall be measured in place and the area calculated in square yards.

(2) New Aggregate: Total number of tons of new mineral aggregate incorporated into the work.

(3) Lime: Total number of tons incorporated into the work.

(4) Asphalt Prime and Curing Membranes: Total number of gallons at 15.5°C (60°F) or tons of material placed.

(5) Mixing, Placing, and Compacting: Total square yards of material placed.

(6) Water: Total number of gallons of water incorporated into the work.

6.0 Basis of Payment

The quantities described above shall be paid for at the contract unit price bid for each item. The above contract prices and payments shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all the work involved in constructing the lime treatment, complete in-place, as shown on the plans, and as specified in the Standard Specifications and these special provisions and as directed by the engineer.

NCHRP GUIDE SPECIFICATION
FOR IN-PLACE RECYCLING OF EXISTING ASPHALT SURFACE AND/OR EXISTING BASE (SUBBASE) EMPLOYING PORTLAND CEMENT STABILIZATION*

1.0 Description

This work shall consist of pulverizing and mixing in-place material, new aggregate (as required) portland cement, and water and spreading and compacting the mixture to the lines, grades, and dimension shown on the plans and/or specified in these special provisions.

2.0 Materials

2.1 Recycled Aggregate: The material to be treated shall consist of a mixture of existing asphalt pavement and the material lying under the pavement. Existing asphalt pavement and stabilized bases shall be ripped and pulverized so that 100% will pass the 37.5-mm (1-1/2-inch) sieve.

2.2 New Aggregate: The new aggregate shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone screenings, mineral dust, or a combination of any of these materials meeting the gradation and quality requirements of the agency.

2.3 Portland Cement: The cement shall be portland cement Type I or Type II as directed by the engineer and conforming to ASTM Specification C150. A certificate of compliance with specifications shall be supplied with each delivery of cement and shall be submitted to the engineer with a certified copy of the weight of each delivery.

2.4 Asphalt Primer and Curing Membrane: The asphalt primer, if used, shall be MC-30, MC-70, MC-250 or RC-70 as specified by the engineer prior to the letting of the contract. The asphalt primer shall meet the requirements of ASTM Specification D2027 or D2028.

The curing seal or membrane shall be an emulsified asphalt selected by the engineer and shall meet ASTM Specification D922 or D2397.

3.0 Equipment

The equipment used for pulverizing the asphaltic material shall (1) be capable of sliding or lifting the said material above the roadway so that the material is suspended in mid-air during the pulverization, and (2) have a cross shaft rotor with pulverizing blades capable of revolving at 750 RPM, or more, during the pulverizing process.

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*The material presented here is taken directly from Reference 6. Where blanks appear, the using organization must develop the required information in order to use the specifications.

If the equipment the contractor plans to use for pulverization does not conform to the above, the engineer shall require a demonstration to prove the equipment capable of pulverizing the asphaltic material to the required size before permitting it on the job.

Except for the pulverization of the asphaltic material, the contractor may use any equipment he selects for mixing the in-place material, cement, and water.

4.0 <u>Construction</u>

4.1 Scarification and Pulverization: The old pavement shall be scarified and pulverized to the depth shown on the plans. Scarification and pulverization can be accomplished in a single pass operation to a depth of about 100 to 150 mm (4 to 6 inches) or a multi-step process can be utilized which consists of scarification, windrowing, and pulverization. All material shall be pulverized such that 100% passes the 37.5-mm (1-1/2-inch) sieve.

4.2 New Aggregate: It may be desirable from a gradation or thickness standpoint to blend two or more aggregates which shall result in a combined gradation meeting the specifications for the finished materials. The materials shall be mixed on the roadbed or on some other approved area off the roadbed by mixing machines or by blade mixing.

4.3 Construction: Cement shall be added at the rate of ____ pounds per square foot and shall be spread by equipment which will uniformly distribute the required amount for the full width of the material to be treated. The rate of cement spread shall not vary more than 10% from the designated rate unless otherwise approved by the engineer.

No traffic other than mixing, compacting, and trimming equipment and water trucks shall be allowed to pass over the spread cement until after mixing, final compaction, and trimming.

The mixing operation shall continue until the material is free of streaks or pockets of cement and the mixture is uniform. Nonuniformity of color reaction, when the material is tested with the standard phenophthalein alcohol indicator, shall be evidence of inadequate mixing.

4.4 Spreading and Compaction: The treated mixtures shall be spread to the required width and grade and shall be ____ inches thick when compacted. The treated material shall be trimmed and compacted to 95% (AASHTO T180), and the contractor may use any equipment he desires to obtain such degree of compaction.

In the event the plans call for more than one lift, the lower lift shall be ___ inches thick and compacted to 95%, but need not be trimmed, before addition of the next lift. Compaction of the lower lift shall be completed within 2-1/2 hours from the time water was first added.

Final trimming and compaction of the top lift shall be completed within 3 hours from the time water was first added.

4.5 Curing: The completed cement-treated base shall be covered with a bituminous curing seal consisting of liquid asphalt, MC-250. The curing seal shall be applied uniformly at a rate between 0.68 and 1.13 litres per square meter (0.15 and 0.25 gallons per square yard), with the exact amount to be determined by the engineer. The curing seal shall be applied on the same day that final compaction is performed and the surface shall be kept moist until the seal is applied. Traffic shall be prohibited from the cement treated material for at least ___ days after completion of construction.

5.0 Measurement

(1) Scarification and Pulverization: The areas scarified and pulverized shall be measured in-place and they are calculated in square yards.

(2) New Aggregate: Total number of tons of new mineral aggregate incorporated into the work.

(3) Portland Cement: Total number of tons incorporated into the work.

(4) Asphalt Prime and Curing Membranes: Total number of gallons at 15.5°C (60°F) or tons of material placed.

(5) Mixing, Placing, and Compacting: Total square yards of material placed.

(6) Water: Total number of gallons of water incorporated into the work.

6.0 Basis of Payment

The quantities described above shall be paid for at the contract unit price bid for each item. The above contract prices and payments include full compensation for furnishing all labor, materials, tools, equipment, and incidentals for doing all the work involved in constructing the cement treatment complete in-place, as shown on the plans and as specified in the Standard Specifications and these special provisions and as directed by the engineer.

NCHRP GUIDE SPECIFICATION

FOR IN-PLACE RECYCLING OF EXISTING ASPHALT SURFACE AND/OR

EXISTING BASE (SUBBASE) EMPLOYING ASPHALT STABILIZERS*

1.0 Description

This work shall consist of pulverizing and mixing in-place material, new aggregate (as required), and liquid asphalt and spreading and compacting the mixture to the lines, grades, and dimensions shown on the plans and/or specified in these special provisions.

2.0 Materials

2.1 Recycled Aggregate: The material to be treated shall consist of a mixture of existing asphalt pavement and the material lying under the pavement. Existing asphalt pavement and stabilized bases shall be ripped and pulverized so that 100% will pass the 37.5-mm (1-1/2-inch) sieve.

2.2 New Aggregate: The new aggregate shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone screenings, mineral dust, or a combination of any of these materials meeting the gradation and quality requirements of the agency.

2.3 Asphalt Binder: The asphalt will be specified by the engineer from the following table prior to letting the contract.

Asphalt	AASHTO Specs.	ASTM Specs.
SS-1, SS-1h	M140	D977
CSS-1, CSS-1h	M208	D2397
RC-70, RC-250, RC-800	M81	D2028
MC-70, MC-250, MC-800	M82	D2027

The engineer will specify the temperature at which the material shall be used.

3.0 Equipment

As many as necessary of the following named pieces of equipment shall be used to complete the specified work: scarifiers; pulverizing equipment; rotary mixers or travel plants; motor graders; windrow devices; aggregate spreaders; power brooms or power blowers, or both; self-propelled vibratory

*The material presented here is taken directly from Reference 6.

or steel-tired tandem and pneumatic-tired rollers capable of attaining the required density; a pressure distributor designed and operated to distribute the asphaltic material in a uniform spray without atomization; equipment for heating the asphaltic material; and a water distributor. Other equipment may be used in addition to, or in lieu of, the specified equipment when approved by the engineer.

4.0 Construction

4.1 Scarification and Pulverization: The old pavement shall be scarified and pulverized to the depth shown on the plans. Scarification and pulverization can be accomplished in a single pass operation to a depth of about 100 to 150 mm (4 to 6 inches) or a multi-step process can be utilized which consists of scarification, windrowing, and pulverization. All material shall be pulverized such that 100% passes the 37.5-mm (1-1/2-inch) sieve.

4.2 New Aggregate: Where mixing of the aggregate is to be done by means other than a travel mixer, any mineral filler or other aggregate to be blended with the recycled material will be spread over the surface of the scarified material in a uniform quantity, and in such quantity as will provide a mixture meeting the gradation requirements. Such applications shall be made immediately after the scarifying operations; mixing with a rotary-type mixer shall continue until a uniform mixture is obtained.

Where a travel mixer is to be used, the prepared recycled material shall be bladed into one or more windrows suitable for the type of travel mixer. Any additional aggregate required to be blended with the windrowed material shall be uniformly distributed over the windrows as directed by the engineer. Windrows shall contain sufficient material to produce the required thickness of compacted pavement.

If all aggregate material is to be imported from local pits or other sources, this shall be spread on the prepared subgrade or placed in windrows (depending on the method of mixing that will be used) in quantities sufficient to produce the required pavement thickness.

Alternative No. 1--Travel Mixing

4.3 Application of Asphalt (Alternative No. 1): Asphalt shall not be applied when the moisture content of the aggregate material exceeds 3 percent, unless laboratory tests indicate that a moisture content in excess of 3 percent at the time the asphalt is added will not be harmful. If the travel

mixer is not equipped to measure and apply the asphalt during the mixing operation, the asphalt shall be applied directly on the measured windrows with the asphalt distributor. When the travel mixer is equipped to measure and apply the asphalt, the applications will be made during the mixing process.

When the travel mixer is equipped to measure and apply the asphalt, the asphalt shall be carefully heated, if needed, by means of heating coils in tanks designed to provide uniform heating of the entire contents. The contractor shall provide all necessary facilities for determining asphalt temperature during heating and prior to use, and shall take all usual precautions incidental to handling these materials.

4.4 Mixing Operation (Alternative No. 1): The aggregate material and asphalt shall be thoroughly mixed until the asphalt is uniformly distributed throughout and all aggregate particles are completely coated. The mixture shall be placed in a windrow for later spreading, aeration, and compaction.

Alternative No. 2 - Blade Mixing

4.5 Application of Asphalt (Alternative No. 2): When the aggregate material is to be mixed with a motor grader, the windrow shall be flattened and the asphalt applied from a distributor. Asphalt shall not be applied when the moisture content of the aggregate exceeds 3 percent, unless laboratory tests indicate that a moisture content in excess of 3 percent at the time the asphalt is added will not be harmful.

The asphalt shall be applied uniformly upon the layer of aggregate material at the rate of 2.3 to 3.4 litres/m^2 (0.50 to 0.75 gal/yd^2) at the specified temperature. The asphalt shall then be initially mixed into the layer. Successive applications of asphalt shall then be applied and mixed in quantities not exceeding 3.4 litres/m^2 (0.75 gal/yd^2).

4.6 Mixing Operation (Alternative No. 2): As soon as the total specified amount of asphalt is applied to the aggregate material, mixing shall be continued with motor graders until a thoroughly uniform mixture is produced.

4.7 Aeration: Regardless of the mixing method used, manipulation of the mix shall continue until volatiles or water, or both, are removed in a quantity sufficient to provide a compactable mix.

When mixing and aerating are complete, the mix may be laid and compacted in accordance with Paragraph 4.7, or it may be placed in windrows along the edges of the area to be paved for laydown at a later time.

4.8 Spreading and Compaction: After the material has been aerated it shall be spread to a uniform grade and cross section and compacted with a pneumatic-tired roller for the full width of the roadway. Rolling shall continue until the entire depth is compacted to the specified density. Test holes shall be dug at specified intervals to determine the compacted thickness of the layers being placed. Areas in which a deficiency of more than 13 mm (1/2 inch) compacted thickness is indicated shall be reworked with added mixed material sufficient to increase the layer to the depth specified. All irregularities that develop in the surface shall be corrected by blading while the pavement is still soft. Blading and compaction shall continue until the surface is true to grade and cross section. The specified in-place density shall be obtained.

5.0 General

5.1 Samples: Samples of all materials proposed for use shall be submitted by the contractor to the engineer. The material shall not be used until it is approved by the engineer.

Sampling of asphalt materials shall be in accordance with the latest revision of AASHTO Designation T40 or ASTM Designation D140. Sampling of aggregate shall be in accordance with the latest revision of AASHTO Designation T2 or ASTM Designation D75.

5.2 Methods of Testing:

(1) Asphalt materials will be tested by the ASTM methods of test.

(2) Mineral aggregates will be tested, as designated in the detailed requirements of these specifications, by one or more of the following methods of test of AASHTO or ASTM.

Characteristic	Method of Test	
	AASHTO	ASTM
Sieve Analysis, Fine and Coarse Aggregates	T27	C136
Unit Weight of Aggregate	T19	C29
Sand Equivalent	T176	C2419
Plasticity Index of Soils	T90	C424

5.3 Weather: Asphalt shall not be applied to the aggregate when the air temperature in the shade is less than 10°C (50°F) unless otherwise permitted by the engineer. Work shall be suspended during rain or when the mix is wet.

5.4 Traffic Control: Traffic shall be directed through the project with warning signs, flagmen, and pilot trucks or cars in a manner that provides maximum safety for the workmen and traffic and the least interruption of work.

Traffic shall be kept off of freshly sprayed asphalt or mixed materials.

If it is necessary to route traffic over the new work, speed shall be restricted to 40 km/hr (25 miles/hr) or less until rolling is completed and the asphalt mixture is firm enough to take high-speed traffic.

5.5 Safety: Safety precautions shall be used at all times during the progress of the work. As appropriate, workmen shall be furnished with hard hats, safety shoes, asbestos gloves, respirators, and any other safety apparel that will reduce the possibility of accidents. All Occupational Safety and Health Act requirements shall be observed.

6.0 Measurement

(1) Scarification and Pulverization: The area scarified and pulverized shall be measured in-place and the area computed in square yards.

(2) Asphalt Primer and Binder: Total number of gallons at 15.5°C (60°F) or tons of each material utilized.

(3) New Aggregate: Total number of tons of new mineral aggregate incorporated into the work.

(4) Mixing, Placing, and Compacting: Total cubic yards of material placed.

(5) Water: Total number of gallons of water incorporated into the work.

7.0 Basis of Payment

The quantities described above shall be paid for at the contract unit price bid for each item. Payment shall be in full compensation for furnishing, hauling, and placing materials for mixing, for rolling, and for all labor and use of equipment, tools, and incidentals necessary to complete the work in accordance with these specifications.

In adjusting volumes of asphalt material to the temperature 15.5°C (60°F), ASTM Designation D1250, ASTM-1P Petroleum Measurement Tables, will be used.

NOTES TO THE ENGINEER

The foregoing specifications for road-mixed asphalt courses are recommended for use under what may be termed average conditions. It is realized, however, that no single standard specification will cover satisfactorily all variations in local conditions which may prevail for individual jobs. Before adopting these specifications verbatim, the engineer, therefore, should give particular attention to the items listed below and, if necessary, make the changes suggested.

Asphalt-sand and asphalt-soil mixed-in-place courses are usually laid to a compacted thickness of from 75 to 150 mm (3 to 6 inches) depending upon traffic conditions. However, greater thicknesses may sometimes be advisable.

Prior to letting the contract the engineer should select the particular asphaltic material he wishes to use, deleting the requirements for all other asphaltic materials shown in these specifications.

Asphalt-sand or soil mixes normally serve better as base courses, but in some localities, because of lack of aggregate and in the interest of economy, they may be used as surface courses.

APPENDIX C
SAMPLE SPECIFICATION FOR HOT-MIX ASPHALT RECYCLING

NCHRP GUIDE SPECIFICATION FOR CENTRAL PLANT RECYCLING OF ASPHALT CONCRETE*

1.0 Description

This work shall consist of removal, crushing, and stockpiling the existing pavement; mixing the processed recycled pavement with new (as required) aggregate and an asphalt modifier (as required) in a suitable central plant; recompacting the disturbed roadway; and placing and compacting the recycled material in conformance with the lines, grades, and dimensions shown on the plans and/or specified in the special provisions.

2.0 Materials

2.1 Recycled Aggregate: The recycled aggregate shall consist of a mixture of existing asphalt pavement and the material lying under the pavement. Existing asphalt pavement and stabilized bases shall be processed such that 100% will pass the 37.5-mm (1-1/2-inch) sieve and 90% will pass the 25.0-mm (1-inch) sieve.

2.2 New aggregate:

(1) Base course. The mineral aggregate for the base course mixture shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone or slag screenings, mineral filler, or a combination of two or more of these materials. The combined aggregate after going through the dryer shall have a sand equivalent value of not less than ____.

Slag shall be air-cooled blast-furnace slag and shall weigh not less than 1.12 Mg/m^3 (70 lb/ft^3).

Mineral filler shall meet the requirements of ASTM Designation D242.

(2) Surface Course. The mineral aggregate for the surface course mixture shall be crushed stone, crushed gravel, crushed slag, sharp-edged natural sand, mineral filler, or a combination of two or more of these materials. __percent by weight of the combined coarse aggregate, other than naturally occurring rough-textured aggregate approved by the engineer, shall consist of crushed pieces, having one or more faces produced by fracture.

*The material presented here is taken directly from Reference 6. Where blanks appear, the using organization must develop the required information in order to use the specifications.

The combined aggregate after going through the dryer shall have a sand equivalent value of not less than ____. Combinations of aggregates that have a history of polishing shall not be used. Coarse aggregate (material retained on the U.S. Standard No. 8 sieve) shall have a percent wear by the Los Angeles abrasion machine test of not more than 40 unless specific aggregates, having higher values, are known to be satisfactory.

Slag, if used, shall be air-cooled blast-furnace slag and shall weigh not less than 1.12 Mg/m^3 (70 lb/ft^3).

Mineral filler shall meet the requirements of "Mineral Filler for Bituminous Paving Mixtures," ASTM Designation D242.

2.3 Asphalt Modifier: The asphalt modifier shall be what is commonly called a softening agent, flux oil, rejuvenator, or soft asphalt cement conforming to the specification for modifier.

2.4 Recycled Mixture: The recycled mixtures shall be an intimate mixture of recycled aggregate, new aggregate (as required), and asphalt modifier (as required) conforming to the mixture requirements. The percentage of new aggregate is not fixed by this specification; however, a job-mix formula must be submitted to the engineer prior to initiation of work and for any subsequent changes in the blend of the mixture.

The job-mix formula for asphalt bound recycled base course mixture shall be within the following limits:

Sieve Size	Total Percent Passing, By Weight
50 mm (2 in)	----
37.5 mm (1-1/2 in)	----
25.0 mm (1 in)	----
19.0 mm (3/4 in)	----
12.5 mm (1/2 in)	----
9.5 mm (3/8 in)	----
4.75 mm (No. 4)	----
2.36 mm (No. 8)	----
1.18 mm (No. 17)	----
600 µm (No. 30)	----
300 µm (No. 50)	----
150 µm (No. 100)	----
75 µm (No. 200)	----
Asphalt Content	---- Percent by weight of total mix

Results of single extraction and sieve tests shall not be used as the sole basis for acceptance or rejection of the mixture. Any variation from the job-mix formula in the grading of the aggregate or in the asphalt content greater than the tolerances shown above shall be investigated and the conditions causing the variation corrected.

The asphalt-bound recycled mixture shall meet the following test criteria:

Stability (Marshall, Hveem):____________________

Flow (Marshall Method):____________________

Swell (Hveem Method):____________________

Air Voids:____________________

Voids in Mineral Aggregate: ____________________

The following tolerances for the job-mix formula will be allowed per single test:

Passing Sieve	Percent
(12.5 mm) 1/2 in and larger	±8
(9.5 mm) 1/8 in and 4.75 mm (No. 4)	±7
2.36 mm (No. 8) and 1.19 mm (No. 16)	±6
600 μm (No. 50) and 300 m (No. 30)	±5
150 μm (No. 100)	±4
75 m (No. 200)	±3
Asphalt content, weight percent of total mixture	+0.5

2.5 Prime Coat: Cutback asphalt for prime coat shall be MC-30, MC-70 or MC-250 complying with the requirements of AASHTO Specification M83 or ASTM Specification D2027.

2.6 Tack Coat: Emulsified asphalt for tack coat shall be SS-1, SS-1h, CSS-1 or CSS-1h diluted one part water to one part emulsified asphalt. Before dilution the emulsified asphalt shall comply with the requirements of AASHTO Specification M140 or M208 or ASTM Specification D977 or D2397.

3.0 Equipment

The equipment shall include: (1) one or more asphalt heating and mixing plants designed to produce a uniform mixture within the job-mix tolerances; (2) one or more self-powered pavers that are capable of spreading the mixture to the thickness and width specified, true to the line, grade, and crown shown on the plans; (3) enough smooth metal-bedded haul trucks, with covers, when required, to ensure orderly and continuous paving operations; (4) a pressure distributor that is capable of applying tack coat and prime material uniformly without atomization; (5) one or more steel-wheeled, pneumatic-tired, or vibratory rollers capable of attaining the required density and smoothness; (6) a power broom or a power blower or both; (7) hand tools necessary to complete the job. Other equipment may be used in addition to, or in lieu of, the specified equipment when approved by the engineer.

The heating and mixing plants shall be capable of producing uniform mixtures at temperatures suitable for mixing additional modifiers and for compaction on the roadway. Furthermore, the heating and mixing equipment shall be controlled to meet existing air quality requirements. Both batch plants and drum mixer central plants can be utilized provided certain modifications are made.

4.0 Construction

4.1 Removal of Existing Pavement and Stockpiling: The bituminous pavement shall be removed in a manner which will prevent unnecessary intermixing with underlying unstabilized base courses. If unstabilized bases are to be

removed they shall be removed and stockpiled separately. Any soft spots encountered during or occurring after removal of existing materials for recycling shall be replaced with suitable materials and compacted.

The storage site and area limits for the bituminous material and base course shall be approved by the engineer prior to stockpiling. The stockpiling area shall be graded and compacted so a firm level base can be maintained at all times. Care shall be taken to avoid contamination of the recycled materials by organic or other deleterious materials.

4.2 Crushing and Stockpiling: The pavement removed for recycling shall be crushed to minus 1 inch. Portable or stationary conventional crushing materials have proven to be satisfactory. Crushing which occurs due to the nature of some pavement removal operations (cold milling operations) are also acceptable.

The crushed bituminous material shall be separated into a minimum of two sizes prior to introduction into the heating and mixing plant. The fine size shall have a minimum of 80% passing the No. 4 sieve. The coarse size shall have a minimum of 60% retained on the No. 4 sieve. Unstabilized base course material shall be stockpiled separately.

The stockpile site shall be approved by the engineer prior to stockpiling. The stockpile area shall be graded and compacted so a firm level base can be maintained at all times and so that the recycled aggregate is not contaminated with the underlying soil. Later stacking conveyors or alternate approved methods shall be used in stockpiling to prevent coning or segregation of component sizes.

4.3 Heating and Mixing: The aggregates which may consist of recycled material and new aggregate shall be heated and mixed in modified plants and drum mixer central plants at temperatures suitable for mixing required asphalt modifiers and suitable for compaction.

If asphalt cement and a softening agent (flux oil, rejuvenator, etc.) are both used as an asphalt modifier a one component system shall be provided

by the manufacturer or the materials shall be introduced into the mixing area through separate metering devices for each material.

A m.. .ıg time consistent with thorough coating of the aggregate shall be used. The moisture content of the bituminous material, sampled behind the lay-down machine prior to compaction, shall not exceed 1.5 percent by weight.

Temperature, total time of mixing, and asphalt mixing time shall be adequate for specified drying, mixing, coating, and compaction but shall not exceed the limits set by the engineer.

4.4 Spreading, Compaction, and Finishing: Conventional asphalt concrete construction equipment shall be utilized as outlined by standard specifications. Weather and seasonal limitations are to be covered by standard specifications for asphalt concrete construction.

4.5 Prime Coat and Tack Coat: Prime and tack coats shall be used as directed by the engineer.

5.0 General

5.1 Samples: Samples of all materials proposed for use shall be submitted by the contractor to the engineer. The material shall not be used until it is approved by the engineer.

Sampling of asphalt materials shall be in accordance with the latest revision of AASHTO Designation T40 or ASTM Designation D140. Sampling of aggregates should be in accordance with the latest revision of AASHTO Designation T2 or ASTM Designation D75. Sampling of the asphalt mixture, as required by the engineer, shall be in accordance with the latest revision of AASHTO Designation T168 or ASTM Designation D979.

5.2 Methods of Testing:

(1) Asphalt materials will be tested by the methods of test of AASHTO or ASTM.

(2) Mineral aggregates will be tested by one or more of the following methods of test of AASHTO or ASTM.

Characteristic	Method of Test AASHTO	ASTM
Amount of Material Finer than No. 200 Sieve in Aggregate	T11	C117
Unit Weight of Aggregate	T19	C29
Sieve Analysis, Fine and Coarse Aggregate	T27	C136
Sieve Analysis of Mineral Filler	T37	C546
Abrasion of Coarse Aggregate, Los Angeles Machine	T96	C131
Soundness of Aggregates	T104	C88
Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test	T176	C2419

(3) The mixture will be tested for asphalt content by "Method of Test for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures," AASHTO Designation T164 or ASTM Designation D2172. The mixture will be tested for compliance with aggregate grading requirements of "Method of Test for Mechanical Analysis of Extracted Aggregate," AASHTO Designation T30.

If the mixture is produced in a mixing plant having automatic controls and a print-out system, and the controls are in proper calibration, binder content compliance will be determined from recorded data. Hot bin analysis together with batch weight read-out data will be used to determine composition compliance.

5.3 Placement Limitations: Asphalt paving mixture shall be placed only when the specified density can be obtained. Precautions shall be taken at all times to compact the mixture before it cools too much to obtain the required density. The mixture shall not be placed on any wet surface or when weather conditions will otherwise prevent its proper handling or finishing. Asphalt surface course mixture shall not be placed when the surface temperature of the base course is below ___°F (___°C). Asphalt base course mixture

shall not be placed when the surface temperature of the underlying course is below ___°F (___°C). Lime, cement, or cold asphalt mixtures shall not be placed when the surface temperature of the underlying course is below ___°F (___°C).

5.4 Traffic Control: Traffic shall be directed through the project with such signs, barricades, devices, flagmen, and pilot vehicles as may be necessary to provide maximum safety for the public and the workmen with minimum interruption of the work.

5.5 Safety: Safety precautions shall be used at all times during the progress of the work. As appropriate, workmen shall be furnished with hard hats, safety shoes, asbestos gloves, respirators, and any other safety apparel that will reduce the possibility of accidents. All Occupational Safety and Health Act requirements shall be observed.

6.0 Measurement

(1) Modifier: Total number of gallons at 15.5°C (60°F) or tons of a) asphalt cement and b) softening agent (flux oil, rejuvenator, etc.) at the job site.

(2) Recycled Aggregate: Total number of tons of pavement material removed and crushed in stockpile.

(3) Recycled Asphalt Concrete: Total number of tons of material incorporated into the work.

(4) Recycled Aggregate--Salvage Value: Total number of tons of removed and crushed pavement materials not utilized on job. With this bid the contractor is the owner of the excess recycled aggregate. The salvage value bid by the contractor will be subtracted from the total bid price if the bid price is positive or added if the bid price is negative.

(5) Asphalt Prime and Tack Materials: Total number of gallons at 15.5°C (60°F) or tons of each material utilized.

7.0 Basis of Payment

The quantities described above shall be paid for at the contract unit price bid for each item. Payment will be in full compensation for furnishing,

hauling, and placing materials; for mixing; for rolling; and for all labor and use of equipment, tools, and incidentals necessary to complete the work in accordance with these specifications.

In adjusting volumes of asphalt materials to the temperature of 15.5°C (60°F), ASTM Designation D1250, ASTM-IP Petroleum Measurement Tables, will be used.

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